Nontraditional User Needs for Surface Deformation and Change (SDC)

NASA Designated Observables (DO) Applications Study

June 2021

Contract No: GS-00F-354CA

RTI Innovation Advisors

Acronyms

The acronyms below are typically defined at first use in the text. They are also defined here for reference.

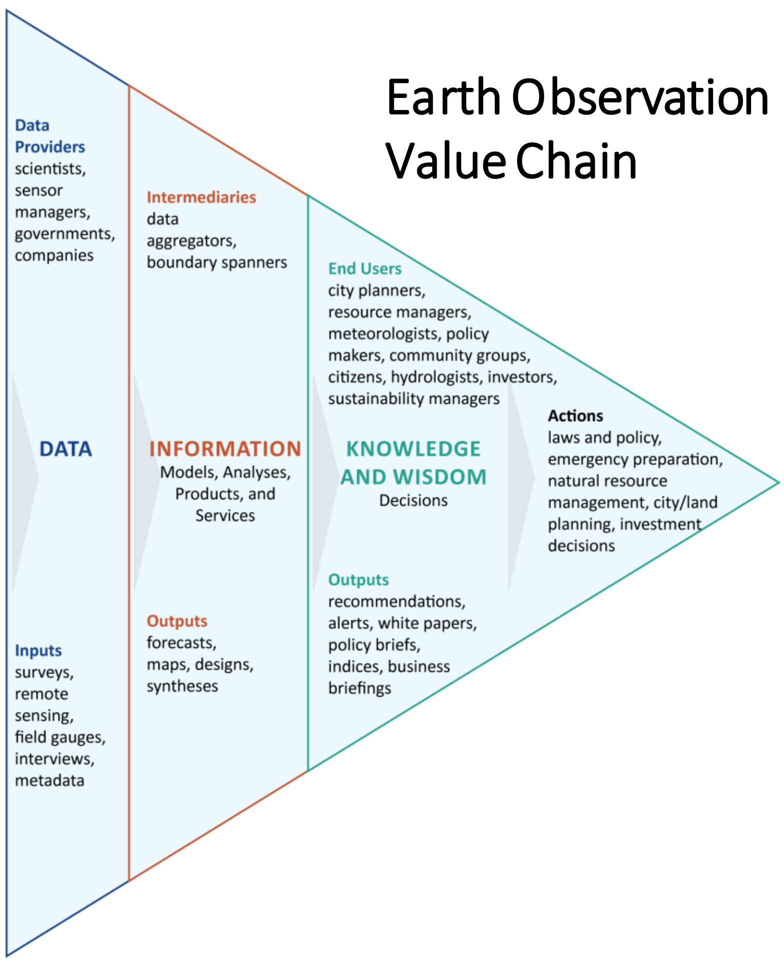
ALOS-2	Advanced Land Observing Satellite-2
CCTV	Closed-circuit television
CSR	Corporate social responsibility
DEM	Digital Elevation Model
DO	Designated Observables
DOE	Department of Energy
DOT	Department of Transportation
EPA	Environmental Protection Agency
ESA	European Space Agency
ESG	Environmental, Social, Corporate Governance
ET	Evapotranspiration
EVI	Enhanced vegetation index
FERC	Federal Energy Regulatory Commission
FEWS	Flood Early Warning System
FMCG	Fast moving consumer goods
GEDI	Global Ecosystem Dynamics Investigation
GIS	Geographic information system
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
InSAR	Interferometric Synthetic Aperture Radar
KOMPSAT-5	Korean Multi-purpose Satellite 5
Lidar	Light detection and ranging
MC	Mass Change
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NGO	Non-governmental organizations
NISAR	Synthetic aperture radar mission being developed by NASA and the Indian Space Research Organization
NLCD	USGS National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
O&G	Oil and Gas
O&M	Operation and Maintenance
OpenET	Open evapotranspiration estimates
PHMSA	DOT's Pipeline and Hazardous Materials Safety Administration
PoR	Program of Record
REITs	Real Estate Investment Trusts
RF	Radiofrequency
S/N	Signal-to-noise ratio
SAOCOM	Satélite Argentino de Observación Con Microondas, Spanish for Argentine Microwaves Observation Satellite
SAR	Synthetic aperture radar
SBG	Surface Biology and Geology
SDC	Surface Deformation and Change
COSMO-SkyMed	Earth-observation satellite spaced-based radar system funded by the Italian Ministry of Research and Ministry of Defense and conducted by the Italian Space Agency
SLC	Single Look Complex
SMAP	NASA Soil Moisture Active Passive
SNOTEL	Snow Telemetry
SWE	Snow water equivalent
STAC	SpatioTemporal Asset Catalog
SDC R&A	SDC Research & Applications Team
TanDEM-X	High-resolution interferometric SAR mission of DLR (German Aerospace Center)
TerraSAR-X	Imaging radar Earth observation satellite that is a joint venture being carried out under a public-private-partnership between the German Aerospace Center and EADS Astrium
TRMM	Tropical Rainfall Measuring Mission
USGS	U.S. Geological Service
VASP	Value-Added Service Provider
VIIRS	Visible Infrared Imaging Radiometer Suite

Sections

RTI uncovered private-sector users across the EO value chain that may use or benefit from SDC-type data.

RTI International, working with the NASA Earth Science Division (ESD) Surface Deformation and Change (SDC) Research & Applications (R&A) Team, conducted this study to capture the needs and priorities of nonresearch Earth observation (EO) data users and potential future users of SDC data. Specifically, the goals of this study were to:

- Bring private-sector user insights to the SDC Designated Observables (DO) team to consider when appropriate during mission design
- Broaden NASA's understanding of nonresearch applications by defining potential user communities, summarizing their current uses of data products, highlighting decisions they make using satellite-based data products (or could make with future satellite data), and providing limitations in terms of awareness and technical realities
- Identify ways in which NASA might engage with these communities



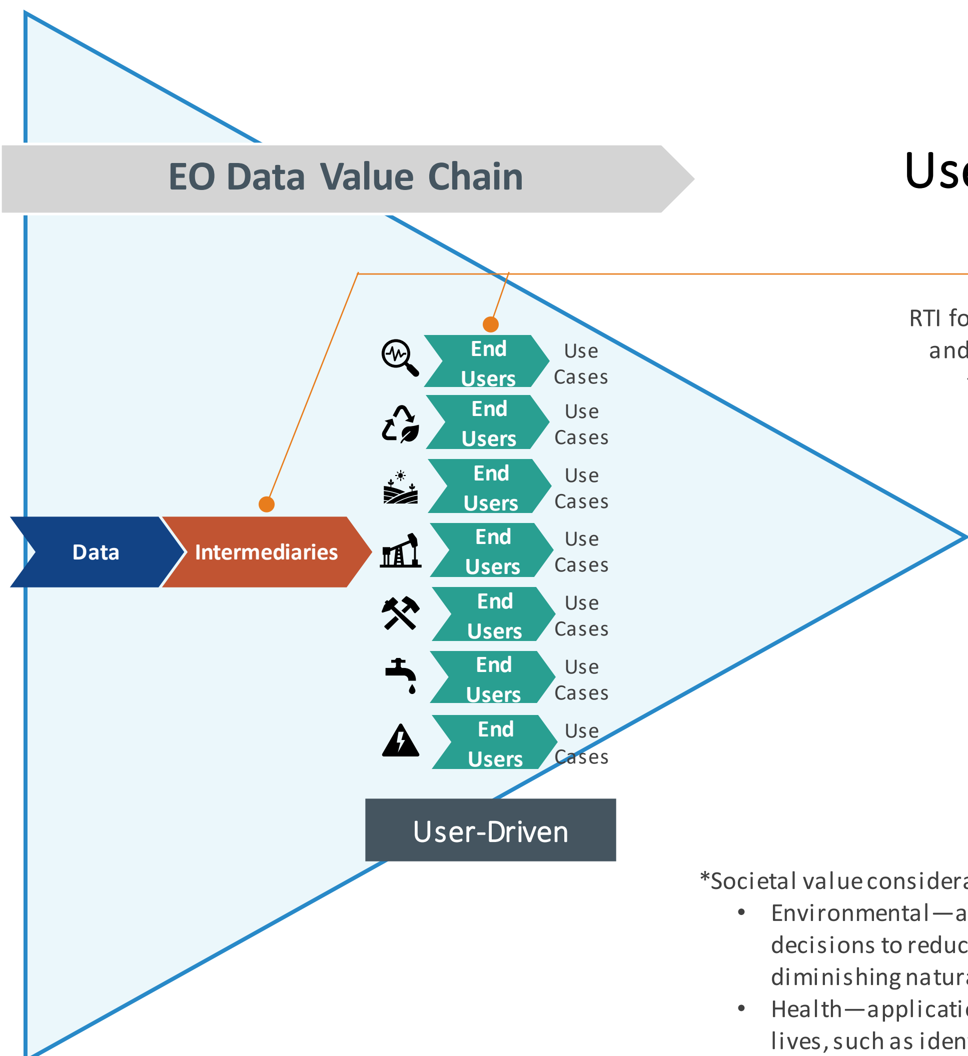
The study considered users across the EO value chain. As concluded by Virapongse et al. (2020),[1] significant opportunities exist across the EO value chain to increase the societal benefit of EO data. Translating data into information for decision-making requires effective presentation and availability of the data for the specific purposes of societal and economic goals. Understanding the needs of and expanding the use of EO data by users in the private sector (e.g., for-profit companies, nonprofit organizations), NASA can ensure its EO data improve decision-making and provide significant societal and economic impact.

The figure to the left, adapted from Virapongse et al., captures the EO value chain and shows how data is transformed by users to information, then knowledge and wisdom, which leads to action. The RTI effort focused on incorporating user perspectives to identify insights and needs across the value chain.

1. Virapongse, A., Pearlman, F., Pearlman, J., Murambadoro, M., Kuwayama, Y., & Glasscoe, M. (2020). Ten rules to increase the societal value of earth observations. Earth Science Informatics. 13. 10.1007/s12145-020-00453-w

This study supported NASA ESD's goal of broadening the use of future EO data and data products.

This SDC study was part of a broader study—which also includes Aerosols, Clouds, Convection, and Precipitation (ACCP) and Mass Change (MC)—that brings potential private-sector user perspectives and desires to NASA ESD DO teams to consider for future mission designs. This study focused on understanding user **desirability** as a key element in user-centered design, which also considers feasibility and viability. Learning what drives users, what key decisions they make, and how they want to access and use the type of data that the DO missions can deliver is the first step toward broadening NASA's nontraditional user communities and increasing the impact of NASA's data.



User-Centered Design

Desirability *(this study)*

RTI focused on uncovering data intermediaries and end users who have needs and desires that could be supported by EO data.

Feasibility

DO teams consider feasibility of nontraditional user desires with respect to DO mission plans and potential data products.

Viability

ESD prioritizes mission efforts based on potential use cases that would best meet NASA ESD's value drivers.*

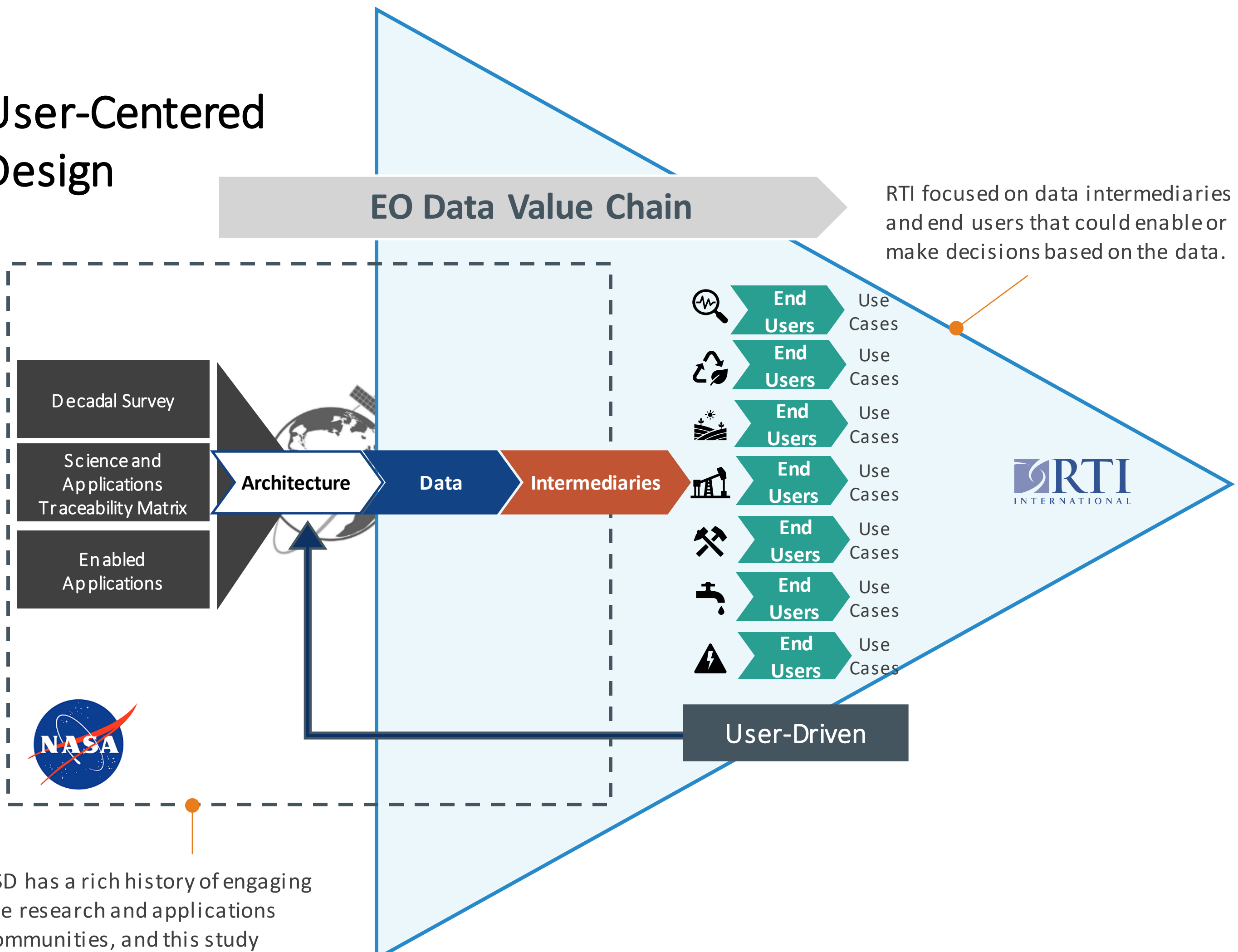
*Societal value considerations may include:

- Environmental—applications that could help users make decisions to reduce environmental damage or preserve diminishing natural resources
- Health—applications that can improve human health or save lives, such as identifying heavy aerosols in the air or providing early warnings for natural disasters
- Economic—applications that could create new products or services, avoid property damage or loss, or reduce risk of job loss by helping companies maintain steady operations

RTI applied a user-centered approach to understand and convey the voices of various user communities.

To extend the impact of future DO data beyond research, this study focused on nontraditional applications of EO data and the associated users along the value chain. Our methodology, detailed in the **Appendix**, was based on a user-centered design framework. This process focused on key user-centered variables—uncovering potential EO end users across multiple industries, characterizing their needs, and learning how they use data to make decisions—to help identify and select user communities and users. This user-centered research was a pilot effort for NASA to consider best practices and methods related to engaging and assessing needs of nontraditional private- and public-sector users early in the mission planning process. This approach enabled the SDC R&A and RTI teams to work together to tackle the task of reaching into and understanding the needs of these communities with guidance and input provided on thematic areas and other topics by the SDC R&A team.

User-Centered Design



RTI focused on data intermediaries and end users that could enable or make decisions based on the data.

ESD has a rich history of engaging the research and applications communities, and this study sought to expand its reach into the applications communities.

RTI and SDC collaborated to select areas of interest, resulting in the selection of seven diverse user communities.

Initial brainstorming with the SDC team, feedback gathered from NASA-Indian Space Research Organization ISRO Synthetic Aperture Radar (NISAR) activities,[1] and the SDC science application traceability matrix (SATM) were used to guide initial outreach to various user communities. After 50 interviews with existing EO data users and NASA experts, RTI prioritized a long list of potential user communities across several factors.[2] The goal was to select communities for profiling that are (1) most likely to value synthetic aperture radar (SAR) data products NASA might provide, which are expected to align with areas SDC may have the highest utility to meet Decadal Survey goals as mapped out in the SDC SATM, and (2) driven by private-sector actors to build beyond research communities already being engaged through NISAR activities. As shown in the figure below, the communities selected and researched span SDC's multiple thematic areas.

User Communities	Property Geohazard Risk Analysis	Sustainable Forestry	Agricultural Field Analysis	Oil & Gas (O&G) Infrastructure Management	Mineral Exploration and Extraction	Water Utility Management	Power Generation and Distribution
	Real estate investors, insurers, marketplaces, and their service providers working to quantify the risks geohazards pose to property	Deforestation monitoring and alert service providers enabling sustainable decision-making in fast-moving consumer goods (FMCG) companies and other organizations	Commercial growers, agribusinesses, crop consultants, insurers, and other agricultural service providers interested in understanding agricultural fields	Oil and gas asset owners and their service providers, who work to reduce environmental and financial risks associated with their infrastructure	Mine asset owners and their service providers, who work to safely and profitability identify and extract minerals from the ground	Water utilities and their service providers, working to efficiently predict and manage local water supply risks and maintain associated infrastructure	Power utilities and their service providers, working to understand and mitigate risks associated with power generation and distribution
SDC Thematic Areas							
Solid Earth	●			●	●	●	○
Hydrology	○		○			●	●
Ecosystems	○	●	●	○	○	○	○
Cryosphere	○			○		○	○

Closed circles (●) indicate thematic areas for which user communities were most interesting in using SDC observables per feedback gathered during this study. Open circles (○) indicate additional thematic areas for which SDC observables were of interest.

1. As per the NISAR Mission Science Users' Handbook, NISAR is a multidisciplinary radar mission to make integrated measurements to understand the causes and consequences of land surface changes activities. Its activities are relevant to this study because many NISAR data users may also be future users of SDC SAR data products.
2. See factors and the associated analysis in the Appendix.

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Research within the seven diverse user communities was distilled into example user profiles and use cases.

NASA SDC and RTI engaged with a targeted cross section of stakeholders across the value chain for each user community to understand their day-to-day roles, their applications of EO data, and opportunities for future data products. The report profiles a selection of users and use cases for each community. Although not exhaustive, these profiles illustrate user and community traits, and are intended to help prioritize opportunities and plan engagement with these communities. Considerations for selecting these representative communities are described in the **Appendix**.

User Community	User Profiles	Use Cases
Property Geohazard Risk Analysis	• **Hazard Risk Model Developer** • **Pension Fund Real Estate Investor**	• Subsidence analysis to inform structural damage risk for commercial property insurers • Subsidence analysis to reduce underestimation of flood risk for pension fund real estate investors
Sustainable Forestry	• **Deforestation Monitoring Service Provider** • **Sustainable Sourcing Manager at FMCG Company**	• Deforestation monitoring to inform sustainable commodities sourcing by FMCG companies • Carbon stock modeling and monitoring to inform forest-based carbon trading
Agricultural Field Analysis	• **Commercial Crop Modeler at Large Agrochemical Company** • **Commercial Corn Grower**	• Global in-season yield projection models to inform seed production decision-making • SAR-based vegetation indices to inform in-season nitrogen managements tools used by growers
O&G Infrastructure Management	• **Technical Lead at SAR-Focused Service Provider** • **Product Manager at Pipeline Inspection Service Provider**	• Interferometric SAR (InSAR) monitoring of transportation pipelines to reduce geohazard risks • Ice hazard analysis to inform response to ice floe risk to offshore platforms
Mineral Exploration & Extraction	• **InSAR Lead at EO-Based Service Provider** • **Mineral Exploration Lead at EO-Based Service Provider**	• InSAR for stability monitoring of tailings dams to ensure safe operations • InSAR for slope stability monitoring at operational pit mines to ensure safe operations
Water Utility Management	• **Hydrogeologist at Water Resources Consulting Firm** • **Asset Manager at Water Utility**	• Soil moisture analysis to optimize drinking water pipeline leak detection and maintenance • InSAR for supplementing Global Positioning System data to inform groundwater pumping limits set by subsidence districts
Power Generation and Distribution	• **Operations Lead at Hydroelectric Power Utility**	• Improved snow extent and snow water equivalent (SWE) data to inform efficient, sustainable hydropower operations • SAR-based detection of power line risks to vector on-the-ground response

NASA has an opportunity to build on its support for SAR communities of practice to help grow broader use of SAR data in the communities.

The table is informed by interactions with a representative selection of users in each community who were engaged through one-on-one interviews and a series of focus groups, during which users discussed their priorities and needs with RTI, NASA scientists, and other users in their community. The following four communities have greater levels of SAR use than other communities profiled in this report.

Key Takeaways	Potential Pathways Forward for NASA
Sustainable Forestry Community	
• SAR brings significant reliability enhancements over optical data because it enables consistent data availability for deforestation monitoring in cloudy regions, especially in the tropics. • Data processors see free data as essential to commercial use cases given their expansive monitoring needs. • Speckling can be a challenge for SAR image quality; tools or data products to address this problem could be valued.	• Prioritize engagement (e.g., workshops designed to ease transition to incorporation of NASA SAR data into workflows based on Landsat or Sentinel-1) here because there is a natural synergy between NASA and community organizations (from EO service providers to FMCG companies buying carbon offset credits) in wanting to tell the story of the power of EO data in enabling sustainable business decision-making. • Address community concerns about switching costs (e.g., normalizing harmonizing data, creating new training data, creating new models) to go from Sentinel-1 to NISAR or SDC and the EO data user experience to ensure NASA SAR data are valued.
Agricultural Field Analysis Community	
• SAR is a current key driver of commercial yield estimate models at large agribusinesses, and it is also used in various other use cases beyond the scale of field management decisions. • Currently, agrochemical companies and value-added service providers (VASPs) spend significant time and internal resources correcting (radiometrically and for elevation) Sentinel-1 SLC files to enable their global use cases. They want to work together to achieve more modern data formats and access methods that make commercial use easier. • In most use cases beyond field management and in some field management use cases, 10-m data products delivered every 2 to 3 to 7 days will be valued. But many decisions at field scale require higher spatial and temporal resolution data.	• Work with private-sector firms to develop next-generation data products that improve use cases for agrichemical firms, farmers, and agricultural insurers. Commercial crop modelers want to have a more technical working relationship with NASA to codevelop data products ideal for commercial use cases. • Recognize that agrochemical companies and VASPs are convinced of the value of EO data in this community, but farmers are relatively unaware and unconvinced of the value of EO data. Work with private-sector organizations to increase awareness of and champion the commercial applications of EO data with end users. Using trusted, existing relationships and communication channels can help NASA go further and faster in this community than they go could alone. • Recognize that farmers are squeezed financially from all directions and that some potential EO data use cases with societal value (e.g., reducing nutrient pollution) do not provide a driver for farmers to learn about and adopt EO-based solutions. Private-sector firms can help NASA delineate science-focused and commercially relevant use cases. Use cases driving real financial value should be prioritized.
O&G Infrastructure Management Community	
• The industry has already adopted InSAR for monitoring of pipelines at specific areas of high geohazard risk (e.g., near fault lines). • Risk tools that provide certainty in decision-making are desired by pipeline owners across all pipelines, not just in high-risk areas. However, limited spatial and temporal resolution, vegetation penetration, and look geometries over the United States have made it challenging for monitoring service providers to deliver "certainty" to O&G clients with Sentinel-1. NISAR or SDC may help expand adoption across long pipeline assets.	• Recognize that organizations in this community may be hesitant to engage directly with NASA. They may be wary of new technology solutions that impose higher costs (e.g., by way of new regulatory requirements they must adopt at their own expense) on their business. • When engaging them, consider the risk they perceive and work to mitigate it. • Consider there may be significant opportunities for cross-agency collaboration between NASA; the Department of Transportation, through the Pipeline and Hazardous Materials Safety Administration; and the Department of Energy efforts to address pipeline monitoring needs; these partners have already built trusted relationships with key end users in this community.
Mineral Exploration and Extraction Community	
• Using InSAR in pit mine and tailings dam stability management has a clear business case, which has led to significant increased adoption of InSAR in the mining industry in recent years. • NASA L-band data will be highly valued because the longer wavelength is key to phase unwrapping procedures for use cases with large deformations; however, users expect to use various SAR bands/resolutions to meet client needs.	• Leading EO-based service providers value NASA, but they are generally well positioned to adopt new NASA SAR products without significant support from NASA. • Recognize that EO service providers want reliable data access and a better use experience (to ensure no delay in informing safety-critical decisions), and they would value communication of longer time horizons for SAR missions to help assure their clients that monitoring solutions are here to stay. • Increase the use of SAR data with research and development collaborations or peer-reviewed research specific to mineral exploration use cases.

For communities of potential, NASA might look for opportunities to provide technical support to improve use of EO data (including, but beyond, SAR).

This table reflects key takeaways and potential pathways forward for the remaining three user communities, which have lower levels of SAR experience and understanding. The table is informed by interactions with a representative selection of users in each community that were engaged through one-on-one interviews and a series of focus groups. Users discussed their priorities and needs with RTI, NASA scientists, and other users in their community.

Key Takeaways	Potential Pathways Forward for NASA
Geohazard Risk Analysis Community	
• Currently, flood risks are the primary concern to risk modelers in the real estate and insurance industries; SDC can improve flood risk models by accounting for subsidence. • Subsidence impact from aquifer drawdown and permafrost melt are of growing concern because of the associated potential for building damage, and commercial property insurers look for ways to capture this risk in their models. • To inform models that forecast future hazards, long time-series, free, expansive data are valued over high spatial and temporal resolution data. • Improved temporal resolution on land cover national maps would improve fire forecasting.	• Recognize that organizations in this community have significantly invested in existing risk models, and they can be risk averse in adopting new models and data sources. Further, those processing EO data for this community may be hesitant to discuss technical modeling approaches with peers. Recognize these factors and develop programs that support that culture. Design programs that organizations are comfortable participating in without expectations for shared visibility into internal processes in return. • Ensure data products enable long time-series analysis (e.g., combining Sentinel-1 and NISAR data easily) to enable the long time-series analysis desired by this community. • Enable developers of flood models in this community, both private and public, by providing technical support to help incorporate subsidence data into their models. • If possible, partner with the U.S. Geological Survey to increase the refresh rate of the land cover national maps, targeting a 1-year update frequency.
Water Utility Management Community	
• InSAR is valued to complement ground-based, spatially limited subsidence measurements in monitoring groundwater depletion, but the cost of InSAR software limits use in this community. • InSAR can improve dam and levee management, and surface water extent may help manage dam flood risk. However, temporal resolution needs are intraday in order to replace existing safety-critical, ground-based sensors. • Higher temporal resolution quad-pol L-band data are desired for polarimetry-based water and wastewater leak detection. • Enhanced SWE data products would improve drought prediction; granular soil moisture data could help manage droughts.	• Work to unlock the barrier to scaling use of InSAR for monitoring groundwater withdrawals. Existing users said the cost of InSAR software is a barrier. NASA should further engage these users to determine if (1) high-level data products from NASA can obviate their need for InSAR processing internally and (2) solutions that reduce the cost barriers associated with InSAR processing for these users can be found.
Power Utility Management Community	
• Enhanced accuracy and coverage area for SWE products would improve hydrogeneration asset management. • Soil moisture, surface water extent, and SAR-based activity monitoring could help manage power distribution risks related to drought and fire and right-of-way management.	**Across both communities:** • Decision-makers value SWE data products. Consider engaging these communities together in the future if NASA gains additional insight into the communities' SWE data product needs. • Using SDC data can benefit these communities, but SDC data play a more complementary role to other EO data in potential use cases than a driver role in many cases. NASA should consider this fact and not lead with SAR data products when engaging this community. • Because they do not have significant EO expertise in-house, utilities rely on external partners, including federal agencies (e.g., NOAA regional river flow forecasting centers) and private-sector consultants to enable their use of EO data products. Ensure that future NASA engagements with this community recognizes this fact. Direct engagement with utilities can help NASA understand their data needs, but utilities will need NASA, other government organizations, or private-sector partners to incorporate EO data into high-level data products before use.

Note that in the context of this report, the property geohazard risk analysis community includes real estate investors, insurers, marketplaces (i.e., an online platform where buyers, sellers, and other real estate stakeholders can interact and learn or share about specific properties), and others working to forecast the risks geohazards pose to property. The study did not focus on organizations that use SAR data to respond to geohazard events, although some companies (i.e., insurance companies) from the property geohazard risk analysis community may also be involved in those activities.

A better user experience accessing EO data and continuity were often on par with, or a higher priority than, specific data attributes across communities.

This analysis reflects the input shared by a representative selection of users engaged through one-on-one interviews and a series of focus groups, during which users discussed their priorities and needs with RTI, NASA scientists, and other users in their community. These takeaways are illustrative, but not exhaustive, of users in each community.

The table below reflects key data attributes and priorities for each user community. User preferences for spatial resolution, temporal resolution, spectral band, and polarization varied not just by community, but also by use case within each community. The values in **bold** in the table do not necessarily work well for all use cases in the community; these **bold** values are instead provided to indicate a value acceptable to most use cases in the community.

Table Legend

Valued Data Attributes	**Valued in Most Community Use Cases** Ranges are (best-case attributed; preferred)—(worst-case attribute where data still valued)
Data Attribute Priorities	Highest Priority Expressed by Community Engaged in RTI Study
	High Priority Expressed by Community Engaged in RTI Study
	Valued But Not a High Priority Expressed by Community Engaged in RTI Study

User Community	**Valued Data Attributes and Priorities**							
	Spatial res.	Temporal res.	Spectral band	Polarization	Latency	Coverage area	Continuity	Other
Property Geohazard Risk Analysis	**10 m** <3–30 m	**7-day** Daily-monthly	**L-band** but others valued	**Dual-pol** single-quad	**Daily to weekly** Low priority	**Global** especially valued outside U.S.	**Long (15–30) year time series desired** though data useful before this point	Higher temporal res. land cover maps
Sustainable Forestry	**10 m** 10–30 m	**7-day** 2–10 days	**L-band** but C-band similar in value	**Dual-pol** dual-quad	**Daily** 1–3 days	**Global**	**PoR-like** in collection and swath	**Better user experience**; SAR-optical fusion tools or products
Agricultural Field Analysis	**10 m** 3–20 m	**7-day** 2–10 days	**Multiband**	**Dual-pol** dual-quad	**Daily** <24 hr–3 days	**Global**	**PoR-like** in collection and swath	**Better user experience**
Oil & Gas Infrastructure Management	**5–10 m** 3–10 m	**7-day** Hourly-weekly	**Multiband** But L-band unique value	**Single pol** Single-quad	**Daily** 2–3 to 36 hr	**Global**	**Long (5–10+) time series desired** for historical analyses	Dual-look geometries and **better user experience**
Mineral Exploration and Extraction	**10 m** 1–30 m	**7-day** Daily-monthly	**Multi-band** but L-band unique value	**Single/multi** Single-quad	**Daily** for safety critical use cases	**Global** to support exploration workflows	**Long time series helpful** for historical analyses	**Better user experience**, dual-look geometries, higher temporal res. DEMs
Water Utility Management	**Variable** 10–100 m	**Daily-Monthly** Daily-annual	**Multi-band** but L-band unique value	**Quad pol** Dual-quad	**Daily** <24 hr–3 day	**Watershed-Regional**	**Long time series helpful** for historical analyses	Lower cost InSAR processing
Power Generation and Distribution	**Variable** 10–100 m	**Daily-Monthly** Daily-annual	Nonspecific	**Dual pol**	**Daily** <24 hr–3 day	**Regional-National**	**Long time series helpful** for historical analyses	Easier path to understand available NASA products

Sections

This study profiled several users and use cases for each user community.

RTI engaged with a cross section of stakeholders across the value chain for each user community to understand their day-to-day roles, their applications for SAR and other EO data, and opportunities for future data products including SDC. The report profiles a selection of users and use cases for each community. Although not exhaustive, these profiles are illustrative and based on direct input from the private sector.

User Community	User Profiles	Use Cases
Property Geohazard Risk Analysis	• **Hazard Risk Model Developer** • **Pension Fund Real Estate Investor**	• Subsidence analysis to inform structural damage risk for commercial property insurers • Subsidence analysis to reduce underestimation of flood risk for pension fund real estate investors
Sustainable Forestry	• **Deforestation Monitoring Service Provider** • **Sustainable Sourcing Manager at Fast-Moving Consumer Goods (FMCG) Company**	• Deforestation monitoring to inform sustainable commodities sourcing by FMCG companies • Carbon stock modeling and monitoring to inform forest-based carbon trading
Agricultural Field Analysis	• **Commercial Crop Modeler at Large Agrochemical Company** • **Commercial Corn Grower**	• Global in-season yield projection models to inform seed production decision-making • SAR-based vegetation indices to inform in-season nitrogen managements tools used by growers
Oil & Gas Infrastructure Management	• **Technical Lead at SAR-Focused Service Provider** • **Product Manager at Pipeline Inspection Service Provider**	• Interferometric SAR (InSAR) monitoring of transportation pipelines to reduce geohazard risks • Ice hazard analysis to inform response to ice floe risk to offshore platforms
Mineral Exploration & Extraction	• **InSAR Lead at EO-Based Service Provider** • **Mineral Exploration Lead at EO-Based Service Provider**	• InSAR for stability monitoring of tailings dams to ensure safe operations • InSAR for slope stability monitoring at operational pit mines to ensure safe operations
Water Utility Management	• **Hydrogeologist at Water Resources Consulting Firm** • **Asset Manager at Water Utility**	• Soil moisture analysis to optimize drinking water pipeline leak detection and maintenance • InSAR for supplementing Global Positioning System (GPS) data to inform groundwater pumping limits set by subsidence districts
Power Generation and Distribution	• **Operations Lead at Hydroelectric Power Utility**	• Improved snow extent and snow water equivalent (SWE) data to inform efficient, sustainable hydropower operations • SAR-based detection of power line risks to vector on-the-ground response

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Each user community has a unique organizational makeup, technical needs, data users, and use cases.

The report synthesizes our extensive user interviews and focus group efforts into community-level summaries that are intended to inform the reader of how they currently or may use Earth observation (EO) data. These insights reflect the perspectives and needs of users across about 50 private companies and nonresearch organizations. Although these writeups are not intended to be an exhaustive summary representative of all possible data uses and use cases within the community, they provides illustrative examples of possible stakeholders to engage, their “personas,” and their uses and needs.

Each user community writeup is divided into five sections:

- The **Community Description** summarizes the community, its stakeholders, and how Surface Deformation and Change (SDC) data may affect the community in the future.
- The **Organizational Assessment** covers the types of decisions made by community members, stakeholders along the value chain, and their general appetite for risk and innovation.
- The **Technical Assessment** covers stakeholders’ needs and priorities with respect to specific synthetic aperture radar (SAR) data attributes and data format/access preferences.
- **Use Cases** demonstrate how SDC data might be used (currently or in the future) to make decisions.
- **User Profiles** provide a “persona” of a potential data user to illustrate how they may use SDC and other EO data.

SDC User Community Profiles

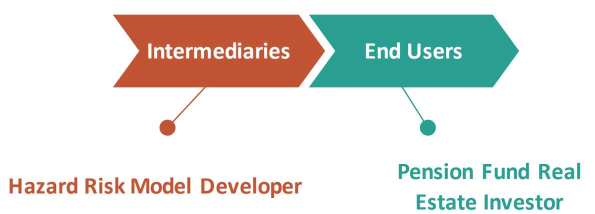
- Property Geohazard Risk Analysis
- Sustainable Forestry
- Agricultural Field Analysis
- O&G Infrastructure Management
- Mineral Exploration & Extraction
- Water Utility Management
- Power Generation and Distribution

User Community: Property Geohazard Risk Analysis

Community Overview

The property geohazard risk analysis community includes real estate investors, insurers, marketplaces (i.e., an online platform where buyers, sellers, and other real estate stakeholders can interact and learn or share about specific properties), and others working to forecast the risks geohazards pose to property. Accurate geohazard risk analysis is needed to appropriately appraise properties, structure property insurance policies, and mitigate and communicate risks to property investors—ranging from pension funds to individual home buyers. The economic and societal impacts of accurate geohazard risk analysis are significant. In the United States alone, the commercial[1] and residential[2] real estate markets combine to exceed $50 trillion in value. Accurate and timely understanding of geohazard risks to these properties helps protect the lives and livelihoods of homeowners and renters, commercial real estate investors, and insurers. The stability provided by risk analysis enables future economic growth.

Selected User Profiles for SDC



Potential Use Cases for SDC Data Products

Subsidence analysis to inform structural damage risk profile of commercial building for property insurer

Subsidence analysis incorporation into flood model to reduce underestimation of flood risk

Moving Forward for SDC

Hazard risk model developers, investors, and insurers need improved data to create and use models that provide confidence in decisions, and ultimately mitigate risk. NASA SDC can provide data of value, especially if its data is able to combine with program of record (PoR) SAR products to enable long time-series analysis.

Based on input via interviews and focus groups, the reality in this community is that expertise with SAR data is relatively low. RTI recommends that SDC consider support of high-level data products to incorporate SAR data (e.g., flood models, land cover maps) to serve this community; most community members, with exceptions, are unlikely to value Level 0 and SLC data products. Beyond SAR, NASA efforts to assimilate data from multiple variable missions into key high-level products, such as flood models, may help simplify workflows and increase trust.

The broader use and adoption of new models to more accurately predict exposure to hazard risks could be driven by (1) unique insights in new products (e.g., high-resolution soil moisture products), (2) improvements to existing products (e.g., higher temporal resolution U.S. land cover product), and (3) clear demonstrations of the benefits of newer approaches. Additionally, this community recognizes the impact of the increasing numbers of climate change events on the portfolio (e.g., increasing number of financial loss events associated with underestimation of risk), which will drive interest in new and improved products.

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RTI Innovation Advisors

User Community: Property Geohazard Risk Analysis

Organizational Assessment

In the context of their decision-making, real estate and insurance firms increasingly recognize the importance of understanding hazard risks, especially those that climate change might exacerbate. The real estate and insurance industries are likely to increase their use of EO data in the future because they already use EO data to inform decisions and they are increasingly interested in understanding hazard risks. Sophisticated risk models—in some cases including remote sensing data—are used today to forecast risks associated with specific properties and to facilitate broader regional and national hazard risk analyses. However, given that organizations in these industries have long used risk modeling to ensure profitability, they may be hesitant to move beyond existing investments in historically profitable tools and processes. One value-added service provider (VASP) mentioned, *"insurers are using models based on 50-year data, but droughts in Germany are changing. They have invested a lot in existing tools. This makes them not want to change. Also, agricultural may be only 3% of their portfolio."* As a result, this predisposition toward existing methods could slow adoption of new EO data products and related hazard risk analysis methods. Broader use and adoption of new models to more accurately predict exposure to hazard risks could be driven by (1) clear demonstrations of the benefits of newer approaches and (2) increasing numbers of financial loss events.

Most organizations in the real estate and insurance industries rely on external data products and models, both free resources from governmental organizations and those purchased via external consultants, to understand aspects of hazard risks. With notable exceptions, internal research teams developing remote sensing–driven risk models are rare at major insurers and real estate firms. These firms do recognize the value of best-in-class hazard risk modeling, but they feel external partners (including other private-sector firms and national or multinational governmental organizations) are best positioned to produce models.

Data	Intermediaries	End Users
Data sources are specific to the geohazard being assessed. For flood risk analysis, data from the **Federal Emergency Management Agency (FEMA)** and **National Oceanic and Atmospheric Administration (NOAA)** are used for modeling in the U.S. **Global Precipitation Measurement (GPM)** (and previously Tropical Rainfall Measuring Mission [TRMM]), **Gravity Recovery and Climate Experiment (GRACE)**, and other data are critical to inform flood models outside of the U.S. For subsidence analysis, **Sentinel-1** is used to inform national-level maps and perform regional analyses. For fire modeling in the U.S., **the U.S. Geological Survey (USGS) National Land Cover Database (NLCD)** is a key data source for fire risk modeling; **U.S. Department of Agriculture (USDA) and local fire models** are also leveraged. **Biomass density maps** are of interest, but specific products used were not identified.	Intermediaries use sophisticated risk models to forecast risks and support decision-making for their clients. Example intermediary users include **Hazard Risk Model Developers** working within an insurance company or as consultants; the risk model developer sources and assimilates EO and other data into models that predict likelihood and severity of hazardous events. Similarly, a **Hazard Mitigation Specialist**, at an engineering consulting firm, works with internal teams or clients to understand and mitigate risks during the site selection and design phases of new buildings and infrastructure projects.	End users making decisions based on EO data include **Pension Fund Real Estate Investors, Risk Engineers at Commercial Property Insurance Companies** (working directly with insurance buyers and converting hazard risk model outputs into insurance policy pricing), **Real Estate Marketplaces** (that may communicate hazard risk to their users, such as homebuyers), and **Actuaries at Index-Based Microinsurance Providers** (who structure parametric microinsurance and coordinate payouts for disaster insurance to lower income people and businesses).
	Profiled in this report	Profiled in this report

User Community: Property Geohazard Risk Analysis

Technical Assessment

Summary: Trustworthy data with global coverage at no cost to access are prioritized over spatial and temporal resolution. For temporal resolution, users need weekly to monthly resolution for most applications. Users prefer 10-m spatial resolution data, but most applications work well with 30-m spatial resolution; generally, the utility of spatial resolution is limited by that of the digital elevation model (DEM).

Current Data Products Used

Flood Modeling: For flood modeling in the United States, members of the property geohazard risk analysis community use FEMA flood and NOAA products. GPM (and previously TRMM), GRACE, and other data are critical to inform flood models outside of the United States (where FEMA data are not available). They might use various regional/local products if they believe they are reliable, accurate, and sufficiently recent.

Subsidence Analysis: Members of the property geohazard risk analysis community use Sentinel-1 to inform national-level subsidence maps and perform regional analyses. They have used TerraSAR-X and other high spatial resolution satellites in narrower (e.g., structure-scale) analyses. They rely on USGS data on for earthquakes.

Fire Modeling: USGS NLCD is a key data source for fire risk modeling in the United States; members of the property geohazard risk analysis community also leverage USDA and local fire models. Biomass density maps are of interest, but companies engaged in the related focus group and interviews did not identify specific products.

Preferred Data Attributes

Spatial Resolution: Users prefer, and deem acceptable, 10-m spatial resolution data products for most applications; sub-10-m resolution is recognized as a potential requirement for specific site analysis (e.g., due diligence on a property before purchase), but this resolution is not needed for regional, national, or global risk modeling. After processing (e.g., speckle removal), 30-m spatial resolution products are acceptable for most risk models, although 10 m is preferred. Users view the resolution of the DEM used in risk models (typically 30 m to 90 m today) as a factor limiting the utility of high-resolution SAR data. Coarse resolution (>30 m) may be used but is of lower value.

Temporal Resolution: Users in this community view weekly revisit as ideal for products, including subsidence and land cover. For land cover, even an annual update to the national map product would provide significant value over the current 5-year update period (this was a leading request from multiple insurance sector modelers). Users desire higher temporal resolution than currently accessible soil moisture data for use in post-event flood condition detection to inform flood model development. With only weekly revisit, a flood condition may develop and resolve between visits; thus, daily revisit is desired to understand where floods have occurred for flood risk modeling purposes. Note that in this use case, low latency (weeks or months) is acceptable because data are not informing flood response.

User Community: Property Geohazard Risk Analysis

Technical Assessment

Preferred Data Attributes (continued)

Spectral Band: Spectral band is low priority. L-band is acceptable for most use cases because higher spatial resolution is not needed, and L-band may provide some benefit in areas with significant vegetation cover.

Polarization: Soil moisture (for flood risk) and land cover (for fire risk) are of interest to hazard risk modelers; thus, at least dual-polarization (dual-pol) or quad-polarization (quad-pol) would be valued.

Latency: Latency is a low priority for developing future risk projection models; monthly is seen as acceptable for most of these use cases. Users desire a time series in the 15- to 30+-year range to inform projection of future risks.

Note that insurance claim payouts (post-event assessment and payment) and disaster response were not considered in detail in this report section (which focuses on future risk projection). High latency in these use cases may save lives and livelihoods. Commercial insurers have a strong need for reliable low latency and high temporal resolution data for these events; they are likely to source commercial data for these use cases when such data are not available from NASA or other agencies. Notably, this commercial data sourcing method may be challenged for microinsurance products (which serve low-income people). Microinsurers (who provide products with down to $1/month premiums) expressed concern that paying for EO data would negatively affect their product pricing such that fewer low-income businesses and people would have less access to affordable insurance; this community, which is predominantly aimed at low- and middle-income countries would also benefit from highly reliable, low latency, high temporal resolution data but has limited ability to pay for data. Puerto Rico is likely an early adopter of microinsurance products in the United States.

Coverage Area: Global coverage over land is highly valued. Model developers work globally, and an ability to employ consistent methods (e.g., only sourcing SAR data from SDC to inform global models instead of sourcing from multiple, variable missions depending on geography) is highly desired to simplify workflows.

Data Formats: Hazard risk model developers would like SLC files to be available and expect to leverage them in their own processing techniques for many use cases; these users would consider use of high-level data products from NASA or other providers if their processing aligns with the specific use case of interest. Other users in the community who may be less familiar with EO data than model developers would likely only use high-level data products. Key products of interest include land use maps, subsidence maps, and subsidence-adjusted flood risk maps; access could be through NASA or partnering agencies.

Other: For existing free SAR sources, data access can be a bottleneck because of how data are cataloged and the time needed to download data. A better user experience is desired.

User Community: Property Geohazard Risk Analysis

Use Cases

Within this community, use cases that may benefit from SDC data products exist and include the following. Use cases with **bold** text have additional detail.

- **Subsidence analysis to inform structural damage risk for commercial property insurers**
- **Subsidence analysis to reduce underestimation of flood risk for pension fund real estate investors**
- Subsidence analysis to monitor structural integrity of coastal protection systems to inform flood risk models
- Land cover data to inform likelihood-of-occurrence component of wildfire risk analysis
- Woody biomass density and height to estimate destructiveness component of wildfire risk analysis
- Soil moisture analysis to inform drought risk component of automated valuation models on real estate platforms
- Soil moisture analysis to inform future flood risk models

Subsidence analysis to inform structural damage risk for commercial property insurers

The challenge: When developing an insurance policy, commercial property insurers want to understand the risks different hazards pose to damaging the building or other property to be insured. Accurately understanding these risks informs policy pricing that balances competitiveness with profitability. Subsidence damage risks are a growing concern to insurers because of subsidence induced by aquifer depletion and permafrost melt.

How EO data might help: In high-risk areas, at least (but potentially globally), insurers desire the ability to incorporate historical subsidence analysis into their risk models to account for potential structural damage to buildings or infrastructure. Insurers are willing to consider investing in producing their own subsidence monitoring tools in-house from SLCs, but they would also be open to using external products that meet their needs.

Key data attributes: Insurers desire monthly refresh of subsidence products or SLCs globally overland because they work globally and benefit from consistent methods across geographies. They prefer 10-m spatial resolution, but 30 m may be acceptable; 3- to 5-m resolution is seen as potentially needed to conduct due diligence for specific properties, as opposed to regional assessment of risks. Long (10+ years) time-series data are valued but not required for use.

Subsidence analysis to reduce under-estimation of flood risk for pension fund real estate investors

The challenge: When managing their portfolio, real estate investors try to limit overexposure to a specific hazard; hazard risk analysis informs investment/divestment decisions to balance portfolio-level risk. Flood risks are challenging for investors to understand today; they worry about underestimating flood risks in areas experiencing subsidence and where coastal protection systems are degrading.

How EO data might help: Incorporating subsidence data into flood risk models can improve confidence that the model does not underestimate risk. Higher confidence will enable continued, sustainable investment in high-risk property areas, will ensure steady returns for pensioners, and may contribute to adoption of resiliency measures.

Key data attributes: Investors desire monthly refresh of subsidence products or SLCs globally overland so they can consider reallocating investments based on flood and other hazard risks quarterly. They need spatial resolution matching the flood model's DEM and prefer 10-m spatial resolution to allow for future DEM improvements, but 30-m resolution would be acceptable today.

Hazard Risk Model Developer

User Community:

Property Geohazard Risk Analysis

Who are they?

Scientists with a background in remote sensing are developing new and improved models to support accurate risk projections across a broad range of hazards.

Who do they work for?

They work within a team of researchers to support internal teams (e.g., risk engineers who use their models to price insurance contracts) or external clients interested in understanding hazard risks in their decision-making.

> *"We work globally. For floods in the U.S., FEMA has good products, but satellite data are important to giving us global scale; it gives us data where data would otherwise be lacking."*
>
> —Hazard Risk Model Developer, Commercial Property Insurer

Hazard risk model developers source and assimilate EO and other data into models that predict the likelihood and severity of hazardous events for their clients.

What decisions are they making (and how) today?

As a VASP within a value chain, these users enable user decisions; however, they must also enable internal decisions within their research team. These decisions include when and how to incorporate new data and modeling techniques into their new or existing models to improve confidence, resolution, or other attributes. Their research team supports decisions that vary by client. For insurance-sector clients, which may be internal or external, these users support risk engineers working to understanding how hazard risks can be priced for insurance contracts; they also work with clients to identify levels of risk and strategies to mitigate risk. For real estate clients (e.g., REITs, pension funds, mortgage brokers), they help quantify risk across asset holdings to inform investment/divestment decisions that balance risks, or they support tools that help communicate risks to different stakeholders (e.g., flood risk indicator incorporation into real estate marketplaces).

To inform these types of decisions, they develop models related to flooding (e.g., coastal storm surge, fluvial floods), wildfire risk (including probability of and potential damage associated with a burn), storm risk (e.g., heavy snow on roofs, mudslides), drought risk, temperature risk, and other risks that may correlate with future hazard-based damages to property value. Models may be unique to specific projects or leveraged across multiple projects.

Do they have experience with EO data?

They either have some or extensive experience with EO data and combine EO data with other spatial data sets in their day-to-day work. They may have a particular focus area or expertise (e.g., hydrology), which gives them a deep understanding of available EO data products and modeling techniques. They may not be familiar with or have experience processing all remote-sensing products (e.g., SAR products), but they are comfortable learning because they realize it may take more time/resources to include fewer familiar products into their models.

What do they want or care about?

They want to build models that give their clients (internal and external) confidence in making data-driven decisions that mitigate risk. In developing models, they care about identifying data products and approaches that will be scalable to all geographies in which they work to save time/resources through consistent processing.

Hazard Risk Model Developer

"Hazards—like floods—actually do strike in the same place twice. We help our clients leverage the historical record of hazard data, from local reports and remote sensing observations, to quantify what has happened in the past to inform their understanding of future risks."

—Hazard Risk Model Developer, Property Risk Platform

"Subsidence and flood risk is starting to enter our radar in recent months. There was a big loss from hurricane Aida, which may be linked to subsidence. And it's also of interest to our structures group, as it can lead to cracking or heavy damage to buildings. So, we could definitely use a subsidence product. It would be a big undertaking to make it ourselves, but even that is something we might consider because of the value."

—Hazard Risk Model Developer, Commercial Property Insurer

What are their technical needs?

They highly value long (10 to 30+ years) time-series data to increase confidence in their models' projections of future risks. When accessing high-level data products (e.g., sea level rise projections), they also value the ability to manipulate model assumptions; they do not like for these products to be opaque in their assumptions. To enable consistent methods across projects, they value global data products, especially outside of the United States; these products prevent them from needing to gather and clean new data sets for all new projects. For any data product, continuity/consistency in data capture is critical to delivering data that can be used in models appropriately. For example, for SAR data, they would value NISAR and SDC data more highly if it could be easily used in combination with other PoR SAR products.

What would motivate them to use NASA EO data?

They are significant users of NASA data today. Moving forward, continuity with the PoR will be key for their use of NASA data products, because all their use cases require significant historical time-series data. For many, the availability of high-level SAR data products from NASA or partners would increase their use of SAR data, because the capability to process SAR data is relatively low today (although this may change moving forward). If NASA could improve existing product characteristics (e.g., U.S. land cover product temporal resolution) or deliver unique insights in new products (e.g., high-resolution soil moisture products), they may be motivated to use the products sooner (e.g., when only 5 years of data are available) than they would otherwise.

What are their adoption barriers for using NASA EO data?

They will be slow to, or never, adopt data products without a long time series. So, products that are new to NASA that align with non-NASA PoR data mitigate a key adoption barrier.

What are they afraid of?

As climate change affects the severity and frequency of hazardous events, they worry their ability to leverage long time-series data to project future risks accurately may be compromised.

What do they NOT care about?

Shorter latency, even when temporal resolution is high, is desired.

Pension Fund Real Estate Investor

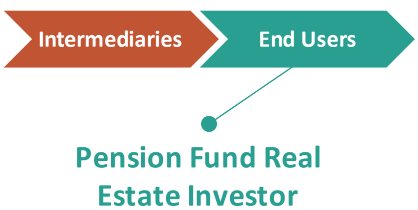
Real estate investors need to understand hazard-based risks to assets across their global portfolio.

User Community:

Property Geohazard Risk Analysis

Who are they?

Often bringing a finance background to decision-making, they work with an internal team to develop and maintain a global portfolio of real estate investments through investment/divestment decision-making.



Who do they work for?

They work for investment teams within pension funds to ensure steady retirement incomes for their clients. Their role is to help manage the real estate exposure of the fund, which typically also invests in other assets.

"Trillions of dollars are at stake in the global real estate market. We need to understand flood risk to protect future economic growth."

—Senior Real Estate Investor, Pension Fund

What decisions are they making (and how) today?

Pension fund real estate investors are making decisions on how to rebalance their portfolio in a changing world to avoid overexposure to any particular risk, while striving for steady returns over the long term. Economic, political, social, technological (including geological), and other factors are used as inputs to the portfolio management decision-making process. Changes in portfolio risk levels are typically assessed at a regular interval (e.g., quarterly), but the global risk exposure is estimated over the long term (including up to 100 years into the future). If overexposure to a specific risk (e.g., flood risk) is identified across the portfolio, actions may be taken to counterbalance the risk; in the flood risk example, actions could include divestment of assets in regions with higher flood risk or investment in assets with lower flood risk. To facilitate the investment or divestment of specific assets, real estate investors may source more granular (e.g., property-specific) data than are used in their portfolio-level review process.

Do they have experience with EO data?

Typically, they do not have direct experience with EO data. They recognize the value these data bring to their risk analyses, and they often have experience leveraging purchased, custom analyses (e.g., subsidence assessments by CGG, flood risk analysis from Climate Adaption Services) or free data products (e.g., FloodFactor, FEMA flood maps) from third parties to inform their analyses. In both scenarios, they rely on third parties to continuously identify and develop the best data and modeling methods.

What do they want or care about?

They care about accurately understanding risks across their global portfolio. Understanding flood risk in the context of a changing climate, including rising sea levels and damage to coastal protection systems, is a primary concern. They recognize there are trillions of dollars at stake in the global real estate market and that climate change is challenging their traditional measures of assessing and mitigating risk exposure. They want trustworthy inputs into their analyses to inform their management of exposure to changing hazard risk levels.

Pension Fund Real Estate Investor

> *"We need to understand where we underestimate flood risk due to subsidence, like in Jakarta."*
>
> —Senior Real Estate Investor, Pension Fund

> *"There's no central data source for levees or other flood protection systems. We know their status in some countries, but in many cases its not clear what was built or if protections were damaged in the last storm."*
>
> —Senior Real Estate Investor, Pension Fund

What are their technical needs?

They can accept weekly or even monthly data product updates, because the updates primarily inform their quarterly portfolio review and risk assessment. They strongly value historical time-series data to increase confidence in decision-making, and they place a low priority on spatial resolution (at least for portfolio management); 30-m spatial resolution is seen as acceptable. Global approaches to risk modeling are desired to bring uniformity to decision-making, but they recognize this technical challenge is hard to solve. Their biggest technical challenge is model reliability. In one example, a real estate investor commissioned physical risk assessment reports from six private-sector risk modeling firms. They selected the two best firms to use in future work, but even these best performing firms often delivered negatively correlated risk assessments to the real estate investor, indicating technical challenges.

What would motivate them to use NASA EO data?

They are interested in using NASA data, and they would trust NASA models more than private-sector models.

What are their adoption barriers for using NASA EO data?

Because they lack technical maturity, these users rely on third parties to produce high-level data products. If NASA or another trusted organization, such as the United Nations, created relevant flood risk and other data products, they would consider using them in addition to, or instead of, third-party models.

What are they afraid of?

They are afraid of both over- and underestimation of hazard risk, threatening their long-term returns and, thus, the retirement income of their clients.

What do they NOT care about?

They do not care about leveraging proprietary data or methods to gain leverage over competing investors. They want data that will reduce the global risk of hazard exposure for all. Yet, because the data are key to their business, they will buy it from third-party providers until governmental organizations make it freely available.

RTI Innovation Advisors

SDC User Community Profiles

- Property Geohazard Risk Analysis
- **Sustainable Forestry**
- Agricultural Field Analysis
- O&G Infrastructure Management
- Mineral Exploration & Extraction
- Water Utility Management
- Power Generation and Distribution

User Community: Sustainable Forestry

Community Overview

The sustainable forestry community includes sustainable sourcing managers for FMCG companies that buy commodities, commodities producers/growers, conservation organizations, carbon market actors, regulators, and deforestation monitoring service providers (who help other organizations in the community benefit from EO data). As a community, they are faced with the challenge of preventing unsustainable forestry management practices (e.g., the clearing of protected forests for grazing, illegal logging) that can result in decreased biodiversity, soil erosion, and increased greenhouse gases in the atmosphere, for example.

Key User Profiles for SDC

Intermediaries: Deforestation Monitoring Service Provider

End Users: Sustainable Sourcing Manager at FMCG[1] Company

Key Use Cases for SDC Data Products

- Deforestation monitoring to inform sustainable commodities sourcing by FMCG companies
- Carbon stock modeling and monitoring to inform forest-based carbon trading

Moving Forward for SDC

Sustainability managers, deforestation monitoring service providers, and others in this community require dependable, global data to monitor forests across their supply chain, and NASA can be well suited to meet this need. Furthermore, because most companies in this community are interested in communicating (i.e., in their marketing materials) their sustainability efforts to different stakeholders (e.g., consumers of FMCGs, investors, potential customers), this community offers an opportunity to increase awareness of the existence and benefit of NASA EO data.

SDC has an opportunity to provide certainty for this community by enabling consistent data capture and access and a commitment to data availability over a long period of time into the future. NASA can help third-party suppliers by communicating plans in terms of commitment to reliability and longevity, as well as communication on operational changes. NASA can commit to maintain free access to SDC data online, with a stated lifetime to ensure long time series. With that, operational data use processes would be worth the commitment to develop for SDC data. In general, these users would value improvements to the user experience, including cloud-to-cloud data transfer to simplify how users evaluate, source, process, and derive insights from EO data. They would also appreciate tools for incorporating NISAR (and eventually SDC) data into workflows that may be Sentinel-1 focused today, which would also help reduce switching costs/increase rate of adoption of NASA data products.

To scale use cases beyond deforestation monitoring, NASA could facilitate an innovation ecosystem to improve carbon stock modeling or otherwise help drive carbon markets that incentivize reduction of greenhouse gas emissions. By helping synthesize EO data (e.g., methane emissions tracking, sustainable agricultural practice quantification) and non-EO data (e.g., land ownership), NASA could improve methods leveraging historical EO data, such that new forest-based carbon credit sellers can join the market sooner.

1. [1]FMCG company

User Community: Sustainable Forestry

Organizational Assessment

Initially driven by conservation organizations, the sustainable forestry community has years of experience using EO data for deforestation monitoring. In the face of climate change and shifting consumer preferences, corporations have continued to become more directly involved with efforts to ensure sustainable forestry practices to maintain the long-term supply of valuable commodities and protect and grow brand loyalty.

In this community, deforestation monitoring service providers are the primary users of EO data. Both nonprofit and commercial service providers are processing EO data globally to monitor deforestation events. They primarily support conservation organizations and those involved with commodities production and purchasing; the role of carbon markets in this sector is relatively new and may play a more prominent role in the future. Although carbon markets broadly are not new, they represent a potential growth area for the use of EO data in this community. The need for action to combat climate change and the maturing EO industry may combine to drive expansion of carbon markets in the future. As carbon markets expand, opportunities for using NASA EO data may increase.

Corporations involved with sustainably sourcing commodities are motivated, in part, by their corporate social responsibility (CSR) and environmental, social, corporate governance (ESG) goals, alongside their desire to ensure a future supply of commodities. Sustainable sourcing practices are often a marketing strategy for specific products to improve brand loyalty and corporate recruiting efforts to help attract and retain talent. As such, these organizations naturally champion their use of EO data, along with other sustainability efforts, to achieve the desired impact on consumers and staff. These organizations present an opportunity for NASA to increase the visibility of the impact of EO data. They are a natural partner because their interest in publicizing the benefits of their use of EO data may positively affect their bottom line and could augment NASA's desire to highlight societal benefits of EO data use.

Data	Intermediaries	End Users
Multispectral, SAR, light detection and ranging (Lidar), and other data are used. Across data sources, users highly value global coverage and free data to enable scalable processes. **Sentinel-1 SLC files** and **Landsat** data are key for driving commercial use cases today. MODIS and Visible Infrared Imaging Radiometer Suite (VIIRS) are less commonly used, but both are used for fire hot spot monitoring.	Private-sector and nonprofit **Deforestation Monitoring Service Providers** drive the leading use case in this community, enabling FMCG companies to make sustainable sourcing decisions. These service providers are expanding to include additional services and are competing with dedicated platforms for **Forest Biomass Platforms to Inform Sustainable Finance** decisions, such as forest-based carbon market trading. These platforms may be general or specific to a given geographic region (e.g., the United States) or biomass type (e.g., mangroves).	End users in this community depend on intermediaries to make decisions based on EO data. These users include **Sustainable Sourcing Managers at FMCG Companies,** who rely on EO data to make sourcing decisions that ensure long-term material availability and achievement of sustainability goals, and **Conservation Nonprofits** who use EO data to drive forward government response to deforestation. An emerging type of user is carbon market actors, including **owners of forest assets** or **companies looking to offset carbon emissions** through the purchase of forest-based carbon credits.
	Profiled in this report	**Profiled in this report**

RTI Innovation Advisors

User Community: Sustainable Forestry

Technical Assessment

Summary: Reliable pass times, stable spectral responses (e.g., stable red band value), and consistent data access are desired alongside "good enough" (10-m) spatial resolution by this community. The community highly values SAR for its ability to provide reliable observations through cloud cover, and L-band is likely preferable to C-band. Dual-pol data are seen as acceptable, but quad-pol data would enable significant benefits.

Current Data Products Used: Currently, monitoring service providers use SAR, multispectral, Lidar (GEDI), and other data.

Historically, Landsat has been a key data source particularly valued for its historical archive, and it is still used by most service providers; Sentinel-2 is growing in use. MODIS and VIIRS are used less often today. They have been valued for getting around cloud coverage challenges due to the revisit rate in the past, but spatial resolution is a challenge because identifying smaller disturbances is hard; both are still valued for fire hotspot monitoring.

The key SAR data source is Sentinel-1, which is typically sourced as an SLC and processed for InSAR coherence; for now, it cannot provide sufficient historical data for some applications, but it is increasingly in use to deal with cloud cover challenges and offers other benefits.

Preferred Data Attributes

Spatial Resolution: Users in this community prefer 10-m SLC files, but they view products ranging from 10 to 30 m as generally sufficient to address most applications, including the ability to detect small-scale clearings. Some areas would value 5 m.

One Sentinel-1 user expressed, *"30 m is usually adequate. 10 m of Sentinel-1 is nice but not necessary for us."*

Temporal Resolution: Although users value subweekly revisit (2 to 5 days), they noted 7 to 10 days is acceptable. Existing users of Sentinel-1 noted SAR offers benefits in areas with persistent cloud cover today, where Landsat may take 30 to 60 days to provide a clear view. For optical products in this community, faster revisit would be desired (faster than every 7 to 10 days) to increase the chances of a timely acquisition.

Spectral Band: C-band is valued, but L-band is preferred. Users said that L-band should provide less noisy data for forest change detection compared with C-band, but that it is too early to say if L-band offers any valuable benefit/advantage over C-band in that use case. They said NISAR will make this clear. X-band is not used today because of cost, and it is not seen as offering significant benefits over C-band. L-band is also valued for its ability to enable more accurate carbon stock modeling and canopy classification (via forest structure/moisture content from the SAR data) to improve forest characterization. This ability is seen as desirable for improving deforestation monitoring and supporting reforestation use cases. Land–water boundaries missed by C-band and optical data now should also be better characterized with L-band, which is expected to improve mangrove and estuary monitoring.

User Community: Sustainable Forestry

Technical Assessment

Preferred Data Attributes (continued)

Polarization: Users prefer and value quad-pol data for improving the characterization of forest degradation. Dual-pol is seen as the minimum number of polarizations to address core use cases in the community. Radar backscatter data are seen as key to distinguishing palm plantation crops in a homogenous canopy where uniform heights and textures exist, because optical data have relatively low utility in this use case; one user noted that having both vertical and horizontal polarizations helps differentiate plans in a tropical canopy.

One user commented on trade-offs in future missions, *"quad is nice, but if it's quad-pol data every 2 weeks vs. dual-pol weekly, I choose the latter."*

Latency: The latency users prefer is 1 day for SLC products, but 1 to 3 days may be acceptable. Consistent latency is highly valued.

Coverage Area: These users prefer data available globally over land. Sustainable forestry often supports supply chain decision-making in tropical regions under persistent cloud cover, so SAR is particularly valued in these regions; however, demand for monitoring outside of these areas is significant as well.

Data Formats: Today, users prefer SLC, in part because standard parameters for high-level products do not always fit established processes because they vary by data provider. High-level products (e.g., atmospherically corrected products) could be valued if consistency across providers is addressed. SAR-optical fusion products are seen as the future of deforestation monitoring, although the same issue related to standardization exists.

One user noted, *"[We] want to process from the highest level possible (like Level 3 products), but because no standards exist, you don't how what you'll get and each [data] provider uses different pre-processors or cleaning; so, the SLC from space agencies is the most stable and therefore easiest to use."*

Other: There is a strong desire for NASA to provide certainty for commercial use cases through a consistent data capture and access process with a clear commitment to a long-term time horizon. Users have faced challenges in the past (e.g., a monitoring service failure) when a file name convention at NASA was changed. They noted that all downstream data processors were negatively affected and that events like this—and unclear continuity years into the future—degrade trust with end users/buyers of EO data–based services.

Free data access is crucial in this community, because monitoring is performed over expansive land areas. Users expressed concerns related to potential future download costs. One noted that buying private-sector multispectral data would roughly increase their service pricing to a typical client by 10 times, which would not be affordable to their clients. They said private-sector data buys also are of concern to large clients who are worry they might build their business decision tools on a data source that may be discontinued.

Users noted the high value of long time-series data being maintained on online archives; they want NASA to understand long time-series data are valued, including for modeling and in increasing trust from their customers.

Users expressed a desire for the simple ability to transfer thousands of files from cloud to cloud.

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User Community: Sustainable Forestry

Use Cases

Within this community, a range of use cases that may benefit from SDC data products exist. Use cases with **bold** text have additional detail.

- **Deforestation monitoring to inform sustainable commodities sourcing by FMCG companies**
- Deforestation monitoring to audit company performance against emissions objectives
- **Carbon stock modeling and monitoring to inform forest-based carbon trading**
- Regrowth monitoring to inform conservation program investments/payments
- Land classification, differentiating forest ecosystems from commercial crops (based on texture and homogeneity) to inform conservation entities managing sustainability

Deforestation monitoring to inform sustainable commodities sourcing by FMCG

The challenge: When sourcing commodities, the origins and thus practices associated with production can be hard to determine; even if they can be determined up-front, practices may change over time. Without a method to assess and monitor the sustainability of commodity producer practices, FMCG buyers' decisions can threaten commodity supplies vital to their firms' long-term profitability and will ultimately fail to hit the firms' carbon targets.

How EO data might help: EO data can help characterize and monitor the sustainability of practices used to produce certain commodities. With easy and continued access to these data, buyers at FMCG companies can ensure they only purchase commodities from sustainable suppliers. By reducing demand for unsustainably produced commodities, FMCG companies can reduce the financial incentive that leads to deforestation.

Key data attributes: Global coverage and persistent monitoring are critical because supply chains are global and complex. Weekly monitoring, 10- to 30-m resolution, and daily latency are acceptable in most cases. At least dual-pol data are required, if not quad-pol. SAR data provide improved reliability and forest characterization and are preferred over optical by some users, but optical data are also useful.

Carbon stock modeling and monitoring to inform forest-based carbon trading

The challenge: Reducing greenhouse gas emissions is one way to slow the impact of climate change; carbon-trading markets have potential to incentivize behaviors that reduce emissions. But carbon markets cannot scale or be fairly run without precise measurements and clear, verifiable methods of accounting for carbon stocks.

How EO data might help: EO data can measure and monitor global forest carbon stocks at sufficient precision and accuracy to inform forest-based components of global carbon market trading. In addition to other EO data (e.g., methane emissions tracking, sustainable agricultural practice quantification) and non-EO data (e.g., land ownership), carbon stock modeling can enable carbon markets, helping to incentivize behaviors to reduce greenhouse gas emissions. EO data may also have an added benefit to paper-based carbon accounting methods for credit sellers. Sellers/landowners may need to collect paper-based data for 5 years today to join the carbon market; with EO data-based methods leveraging historical EO data, new sellers may be able to more quickly join the market.

Key data attributes: Because of its vegetation penetration, L-band data are seen as preferred for estimating global forest carbon stocks from SAR data. Trustworthy global data products and accounting methods will be needed to enable a scalable, sustainable carbon-trading market, so public data sources are preferred.

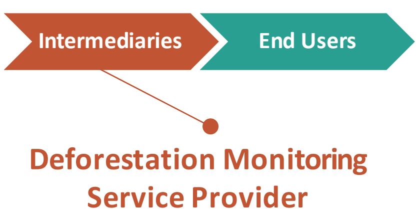
Deforestation Monitoring Service Provider

User Community:

Sustainable Forestry

Who are they?

Scientists with a background in remote sensing are building new processing techniques and products to support their clients' sustainability efforts.



Who do they work for?

They work for a range of conservation-oriented clients, from FMCG companies to commodities producers to nongovernmental organizations (NGOs) to government.

> *"We almost entirely rely on SAR now for deforestation monitoring, as you can get it regardless of weather, unlike optical. SAR is ultimately more sensitive to change and can give more time sensitive deforestation alerts."*
>
> —Deforestation Monitoring Service Provider

Deforestation monitoring service providers build EO-based tools to help characterize and monitor forests for their clients.

What decisions are they making (and how) today?

Internal decisions include when and how to incorporate new data and workflows into their services. For FMCG sustainable sourcing clients, services are used to vet new suppliers and continuously monitor existing suppliers, potentially leading to a decision to discontinue a supplier relationship. They may also support tracking of progress against zero-deforestation or carbon commitments for these clients. In the nonprofit community, they support research and grievance report development. For law enforcement, their monitoring services can target areas for on-the-ground follow-up. For policy and conservation finance clients, they inform understanding of areas most affected by deforestation to triage investment priorities and inform carbon markets.

Do they have experience with EO data?

They have extensive experience with EO data for deforestation monitoring. They may have limited to extensive experience with SAR data (varies by service provider).

What do they want or care about?

They want increased reliability and ease in data access methods. They see free data and data access as crucial to the viability of their monitoring services, and they highly value space agencies' ability to deliver consistent low- to no-cost data products.

What are their technical needs?

Their primary technical need is increased reliability and ease of access. They would also be interested in and could benefit from despeckling tools/despeckled data because speckling is a challenge that negatively affects consistent SAR data. They see SAR-optical data fusion tools and fused data products as interesting in the future as well. But before using high-level data products beyond SLCs, they need to see significant improvement in the standardization of high-level products across data providers.

Deforestation Monitoring Service Provider

"We experienced huge switching costs in moving to SAR as our primary data source. Had to do it once changing from Landsat to Sentinel … If there's a way to avoid this [for NASA data] it would be a huge advantage."

—Deforestation Monitoring Service Provider

"In my current free data workflow, I might need to charge a client $200k for a monitoring service per year. If I had to buy data, that would go up to $2M per year. The business model would not work. So, we really value agency data."

—Deforestation Monitoring Service Provider

"We need mature, stable data, and communication about APIs and changes. The EU tendered that service to five consortia which diluted the resources, recognizing the risk of going with one industry partner."

—Deforestation Monitoring Service Provider

"Big clients, like Cargill or Shell, look at tomorrow but also many years ahead. A start-up that might not survive is an issue [for them]. Government-funded solutions create a viable ecology for start-ups to survive."

—Deforestation Monitoring Service Provider

What would motivate them to use NASA EO data?

They would be motivated to use NASA data by the benefits L-band offers over C-band, as well as the ability to increase temporal resolution of their monitoring service alerts.

What are their adoption barriers for using NASA EO data?

They are either in, or recently experienced, a transition from optical only to including SAR data flows for deforestation monitoring (e.g., from Landsat to Sentinel). They invested significant time and resources in normalizing/harmonizing these data, creating new training data, models, etc. They need support tools for incorporating NISAR, and eventually SDC, data into their workflow to reduce switching costs. Without these tools, adoption may be slow, especially if core use cases experience only modest benefit from incorporation of L-/S-band along with or instead of C-band. The level of benefit is not yet clear. They view switching costs as a significant barrier to future NASA SAR data use.

What are they afraid of?

They are afraid of costs of data access increasing in the future and the uncertainty of data continuity over long time horizons (beyond 5 to 10 years).

What do they NOT care about?

They do not see much benefit from small improvements on spatial resolution.

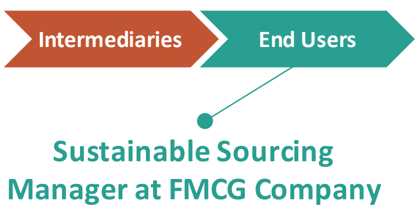
Sustainable Sourcing Manager at FMCG Company

User Community:

Sustainable Forestry

Who are they?

Supply chain managers with a background in sustainability are excited about ensuring their products are sustainable to meet their consumers' expectations and ensure future raw material availability.



Who do they work for?

They work with the internal supply chain team buyers to support sourcing decisions and corporate ESG/CSR leads to meet reporting requirements.

> *"Current [deforestation monitoring] data have high coverage, but resolution leaves a lot to be desired; and cloud cover presents real challenges."*
>
> —Sustainable Sourcing Manager, FMCG Company

Sustainable sourcing managers work with buyers to ensure their products' supply chains are sustainable with respect to land, water, and climate impacts.

What decisions are they making (and how) today?

Sustainable sourcing managers work directly with buyers in their internal supply chain team to decide where to source specific commodities (e.g., palm oil, cocoa beans) globally. When setting up new supply chains, they work with on-the-ground partners and other data sources to ensure they understand the true source of commodities (e.g., to understand where trees originate from before arriving at mills used to process them). Once harvest sources are identified, they work with deforestation monitoring firms and other data sources to ensure those locations are not associated with deforestation.

Once supply chains are established, they continually monitor them to ensure they remain sustainable. To do this, they subscribe to paid deforestation monitoring services to detect deforestation events associated with their existing supply chain; alerts from these services trigger internal investigations that may lead to changes in vendors.

Do they have experience with EO data?

They have limited to no direct experience processing EO data, but they understand the benefits and limitations of different monitoring services and products available to inform their decision-making.

What do they want or care about?

They want a simple internal workflow to ensure they can monitor and make decisions across their complex, global supply chains. They highly value dependability in monitoring services.

What are their technical needs?

They need deforestation and wildfire monitoring tools that integrate easily into internal supply chain management tools. Products built from existing 10 to 30 m are generally acceptable. They highly value reliability and work extensively across global regions with persistent cloud cover to source palm oil, cocoa, rice, etc., so they value data that can reliably penetrate cloud cover.

Sustainable Sourcing Manager at FMCG Company

"We need sustainable sources to ensure we have access to materials we need in 5–10 years."

—Sustainable Sourcing Manager, FMCG Company

"We monitor deforestation, but also child labor in cocoa regions, drought in Australia for dairy sourcing, floods in the Midwest for sugar beets, and more. We monitor all aspects of sustainability across our supply chain."

—Sustainable Sourcing Manager, Food and Beverage Company

What would motivate them to use NASA EO data?

They do not have a strong preference as to the originator of data sourced by their supplier of deforestation monitoring (e.g., NASA, ESA, private-sector satellite data provider). They are motivated to access deforestation monitoring and alert services that best integrate with their internal supply chain management tools and provide value.

What are their adoption barriers for using NASA EO data?

They are not direct decision-makers in the sourcing of low-level data products; they depend on their deforestation monitoring and alert service providers to evaluate, source, process, and derive insights from EO data. As one sourcing manager described, *"I could use NASA SAR data if my third-party supplier used it; but not before."*

What are they afraid of?

They are afraid of both short- and long-term economic pressures and their ultimate financial success. Their concerns relate to both access to materials in the supply chain and sustainability commitments and brand benefits. Beyond access to a cost-effective and steady supply, they are afraid of incorrectly understanding linkages between their supply chains and sustainability goals set by the firm and brand(s) they support. If they are not able to appropriately guide sourcing decisions to meet public sustainability goals as laid out in their ESG/CSR strategy, it may lead to decreased brand loyalty from consumers (decreasing sales) and other potential negative financial effects associated with failure to meet ESG/CSR goals.

What do they NOT care about?

They do not care about the source of the data that their service providers use.

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SDC User Community Profiles

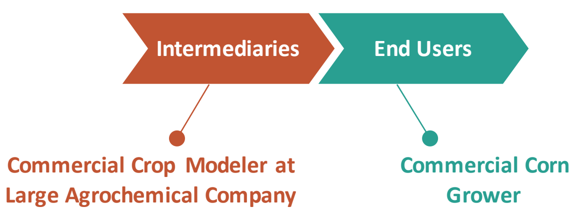
- Property Geohazard Risk Analysis
- Sustainable Forestry
- Agricultural Field Analysis
- O&G Infrastructure Management
- Mineral Exploration & Extraction
- Water Utility Management
- Power Generation and Distribution

User Community:
Agricultural Field Analysis

Community Overview

The agricultural field analysis community includes farmers, agrochemical companies, crop consultants, crop insurers, and other agricultural equipment and service providers. In this community, EO data inform decisions across a wide range of temporal and spatial scales. On one end of the spectrum, commercial farmers are focused on understanding the optimal way to manage crops on their field; on the other end, large agrobusinesses firms are working to analyze all global fields (e.g., to estimate the yield for a specific crop). NASA EO data afford a range of opportunities in this community, including SAR data, to complement a growing number of commercial EO data sources. Opportunities relate to improving options for farmers, crop modelers, and other users to increase profitability, reduce environmental impact, and improve food security.

Key User Profiles for SDC



Key Use Cases for SDC Data Products

Global in-season yield projections models to inform seed production decision-making

SAR-based vegetation indices to inform in-season nitrogen management tools used by growers

Moving Forward for SDC

The range of SAR expertise is significant within this community. Agrochemical companies and VASPs build sophisticated, operational models that drive grower decision tools and internal decision-making today; growers, farm insurers, and other users have a relatively low awareness or understanding of EO data. SDC has two main opportunities: (1) work with the community's SAR/EO experts to develop data products and interfaces that enable increased commercial use for agricultural field analysis and (2) partner to raise awareness and message value to end users. Regarding (1), community SAR/EO experts expressed they want to be part of substantive, technical, pragmatic collaborations that go beyond science-oriented discussions and focus on developing reliable, robust data products and workflows for commercial use cases. Partnerships could relate to achieving more modern data formats, including geometrically corrected data products, products aimed at agriculture-specific use cases, cloud-based cropping tools, and simple cloud-to-cloud transfers. Also, as with other communities, SDC should build forward with continuity with the PoR (e.g., such as Sentinel in terms of collection time and swath). Regarding (2), NASA could partner with companies that already have relationships with growers (e.g., agrochemical companies) to combine to build trust and adoption. If end users better understand how EO-driven applications can benefit them, it will enable greater adoption. Adoption will require end user behavior change and investment. To drive adoption, benefits must be significant and specific to real business decisions.

User Community: Agricultural Field Analysis

Organizational Assessment

Risk tolerance and technical ability to process EO data vary significantly within this community. On one end of the spectrum, commercial crop modelers at large agrochemical companies and professional services firms have teams dedicated to exploring and operationalizing EO data for viable commercial use cases. They are willing to experiment with new data if they see a clear potential business case for its use. On the other end of the spectrum, commercial growers are necessarily risk averse; they cannot afford to take risks that affect their livelihood (e.g., their crop yield for the season). Without clear benefits and low risk of adoption (e.g., demonstrated to work in their soil type, region, crop hybrid), they will not adopt new technologies.

Commercial crop modelers are the core current and future users of satellite EO data for field analysis in this community. They may process these data for use by growers in precision agriculture applications, enabling growers to manage their land in a site-specific way, or they may process the data for a range of nonprecision agriculture use cases, including planning production for and marketing agrochemical products and monitoring crop damage for insurance payments, for example. These commercial crop modelers have significant expertise employing satellite and other remote-sensing data to develop global-scale and regional crop models and decision tools. These users are a potential resource for NASA to help develop data products and interfaces that enable increased commercial use of EO data. They highly value NASA data and other free data sources because their global models (e.g., global yield models for corn) employ large quantities of data that would be expensive to procure from commercial suppliers. Although commercial growers may benefit from NASA EO data, they are not likely to access even high-level data products directly from NASA. Growers rely on existing relationships and trusted information sources to learn about and consider adoption of new technologies. The best way to increase their use of EO data is to make these data more easily available and useful for their existing trusted information sources and technology providers. These organizations include both the private sector (e.g., agrichemical companies, agricultural equipment companies, crop consultants) and the public sector (e.g., agricultural extension programs, USDA).

Data	Intermediaries	End Users
Data are sourced/combined from various global providers. **Optical data sources from government (e.g., ESA's Sentinel-2, NASA/USGS's Landsat-8) and commercial (e.g., Planet's Dove) providers** are used. For **SAR data, both low (e.g., Sentinel-1, ALOS-2) and high (e.g., TerraSAR) resolution** data are used depending on the use case.	**Commercial Crop Modelers at Large Agrichemical Firms** and **Smaller, EO-Focused Service Providers** evaluate and assimilate large EO and on-the-ground data into practical, reliable tools to inform internal (e.g., agrochemical marketing or production teams) or client decision-making. These modelers are sophisticated EO data users, typically having previously completed a PhD related to using EO data for informing agricultural decision-making.	Commercial growers, like **Commercial Corn Growers,** have limited to no direct experience with collecting or processing EO data; they may work with **Extension Programs, Agronomists,** or private-sector **Decision-Tool Providers** who may help them access these insights. Other users include **Risk Managers at Crop Insurance Providers** who work to balance customer satisfaction and risk when deciding which claims to investigate before payment; EO data could help them verify and deploy teams more quickly.
	Profiled in this report	**Profiled in this report**

User Community: Agricultural Field Analysis

Technical Assessment

Summary: In the agricultural field analysis community, SAR is of interest because it is reliable (owing to cloud penetration) and able to provide insight into field characteristics (through SAR backscatter) not well observed with optical imaging. At ~10-m spatial resolution and a weekly repeat rate, SAR missions with globally available data can be of significant value, while many research and development (R&D)-focused use cases exist at even finer spatial resolutions, including submeter. Many field management decisions (e.g., fertilizer application) are limited by resolution of the tractor-mounted applicator, which commonly ranges from 10- to 20-m resolution in commercial farming. Key areas of interest for SAR are connected to its ability to differentiate crop types and phenology to inform a range of decisions—from global yield projections to precision field management—and soil characterization to detect flooding or ponding in flat areas, as well as other attributes.

Current Data Products Used: To understand vegetation growth, MODIS vegetation index products—Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI)— are used, as are myriad other similar products built from other optical data sources from government (e.g., ESA's Sentinel-2, NASA/USGS's Landsat-8) and commercial (e.g., Planet's Dove) providers. SAR-optical fusion vegetation index products, as well as SAR-only vegetation index products, exist and are of interest, but they are not yet commonly used. Sentinel-1, ALOS-2, SAOCOM, TerraSAR, and Radarsat are used in various use cases, including in-season yield projections, which value SAR-based phenology determinations and soil moisture assessment. Global DEM products, as well as more local (e.g., from state government) Lidar, are used to inform map creation.

Preferred Data Attributes

Spatial Resolution: To inform many key use cases in the agriculture field analysis community, including yield estimation, crop classification, and crop damage assessment, 10-m spatial resolution SAR data are acceptable. For field management decisions, 3 to 7 m may be ideal, offering benefits beyond 10-m data, which can lead to more coarse data products after processing. For global yield and other models, <10-m data benefits are less valuable.

At present, there is a practical limit on 10-m resolution (after data processing/speckle removal) after which the benefit of higher resolution wanes for many field management applications of EO data. This limit is imposed by input application equipment (e.g., a tractor-mounted fertilizer spreader) owned by farmers; this equipment typically has resolution of 10 to 20 m. Because of the resolution limits of this equipment, there is limited benefit to data products with higher spatial resolution for most farmers, although this limit may change in the future.

Key exceptions that demand higher resolution include R&D use cases (e.g., plant counting, disease detection) and all use cases that involve smallholder farms. For these use cases, significant benefits would be derived from <10 m (down to ~1 m or even <1 m) data.

User Community: Agricultural Field Analysis

Technical Assessment

Preferred Data Attributes (continued)

Temporal Resolution: The desired temporal resolution varies significantly across use cases within this user community.

For global yield monitoring of row crops, tillage practice monitoring, and structuring crop insurance policies, users view weekly repeat as acceptable. Existing crop yield models by agrochemical companies include 10-day to 18-day revisit data. Users said that improving beyond weekly revisit rates offers minimal benefits to yield models in global, nonfield management decision-making.

For many precision agriculture or field management decisions, a higher revisit rate offers significant value. For crop damage assessment and variable rate fertilizer application, a daily revisit rate is ideal, with data still useful at up to a 6-day revisit rate. Notably, high temporal resolution SAR-based crop damage assessment and flood detection post-storm can offer significant value in informing storm response by the farmer, insurer, and other actors because SAR sees through clouds associated with damaging storm events that obscure optical imaging. This value may be reduced, though, if the revisit rate is slower than the length of time cloud cover persists post-storm.

For irrigation field management decision-making, 1- to 2-day or intraday revisit is ideal; data are seen as potentially useful at slower repeat rates because different data sources, including other remote-sensing data and on-the-ground data, may be combined to inform decision-making. However, data are of little or no value for field management after 6 days.

Spectral Band: Agricultural use cases benefit from a variety of SAR and other spectral bands. The field analysis community has a strong desire for multiband SAR data. Of the SAR bands, L-band is particularly useful, compared with X- and C-band, for crop classification (because it can better distinguish between crop classes) and for soil analysis (including soil moisture analysis) because of its ability to penetrate denser crop canopies. Leading agrochemical firms noted that if they had to choose one spectral band, they would likely choose L-band for crop classification and soil moisture over X- and C-band. They would choose X-band for detecting in-field ponding and crop lodging. But users stressed significant benefit would be derived from multiband SAR availability. Multiple current SAR data users expressed interest in P-band to provide deeper insight into plant and soil properties; one noted P-band does not appear to be of interest to commercial SAR vendors.

Polarization: Analysis of SAR backscatter is critical in agricultural use cases. Backscatter can act as a proxy for leaf area index to produce vegetation index products, inform yield projections, and inform a variety of other existing commercial use cases. SAR vegetation index products may also provide insight where optical-based NDVI data are hard to interpret (such as for apples, grapes, pears, kiwis, and prunes). Backscatter may also be key to potential use cases that are not yet commercialized in the community, including soil salinity analysis based on the spatially variable dielectric constant of soil. All agrochemical and field analysis companies interviewed expressed a strong desire for quad-pol SAR data, but they also noted dual-pol would still be useful.

User Community: Agricultural Field Analysis

Technical Assessment

Preferred Data Attributes (continued)

Latency: Like temporal resolution, importance of latency varies considerably between use cases. For irrigation decision-making; response to extreme weather events, including by farmers, insurance companies, and their partners; and other field-management use cases, low latency is critical; 1-day or intraday data are desired. One crop advisor explained that with current NDVI products, waiting 2 to 3 days to crunch numbers, "breaks" some potential field management use cases because farmers cannot afford to wait 2 to 3 days.

For many use cases such as yield projections, crop classification, tillage practice identification, and soil analysis that inform crop planning, as opposed to in-season field management, latency is less critical; for these, 1 to 3 days or more is acceptable, although daily is preferred and faster is valued.

Coverage Area: These users value global coverage over land. Many model developers work globally, and global data availability allows better scalability of SAR-based methods across geographies. Along with the United States, northern Brazil, Southeast Asia, and the Niger Delta region are all major agricultural production areas under persistent cloud cover; in these regions, SAR products will be particularly valuable because they can penetrate clouds.

One agrochemical company noted: "*California has plenty of cloud-free days. But not Washington, Oregon, or Brazil. In some areas, Sentinel-2 might give us one good picture in a year.*"

Data Formats: In general, agrochemical companies and other model developers are interested in working from SLC files to build their own crop models. Agronomists, who advise farmers on decision-making, are unlikely to build their own models. To derive insights from SAR data, they may benefit from high-level data products (e.g., SAR vegetation index products, SAR-optical fusion vegetation index products) to inform their advice to farmers. They may be interested in accessing these from federal government agencies or commercial partners such as agrochemical, farm machinery, and decision support firms.

Other: Regarding data access and preprocessing, multiple agrochemical firms noted that significant internal time and resources are spent downloading unneeded data (e.g., 100- x 100-km scenes when only 10 x10 km are of interest) and correcting Sentinel-1 for elevation. They would be interested in NASA providing (1) cloud-based cropping tools, (2) geometrically corrected data products, and (3) simple cloud-to-cloud transfers (e.g., for thousands of files). These tools and improved data products would simplify their workflows.

They explained that they would highlight value cleaned, SpatioTemporal Asset Catalog (STAC)-compliant SAR analogs to those optical products available in a cloud environment. They also noted that SAR data are not easily combined with established optical imaging archives and that this technical challenge could be a barrier to SAR adoption.

Regarding continuity with the PoR, companies expressed that it is a high priority for future NASA SAR missions to be like Sentinel in terms of collection time and swath. They also noted significant value in having multiple SAR bands on the same track to better enable combining bands in their use cases.

User Community: Agricultural Field Analysis

Use Case

Within this community, use cases for SDC data products exist. Use cases with **bold** text have additional detail.

- **Global in-season crop yield projection models to inform seed production decision-making**
- Global in-season crop yield projection models to support government or NGO food security activities
- Global crop classification to inform targeted marketing of crop protection products
- Global crop classification to inform replant decisions for specific crops (e.g., apples)
- **SAR-based vegetation indices to inform in-season nitrogen management tools used by growers**
- Crop damage assessment to inform efficient and fast assessment of crop insurance claims
- Crop damage assessment to inform fast farmer intervention/response
- Tillage practice identification to inform conservation monitoring or actions (e.g., subsidy payments)
- Tillage practice identification to inform targeted marketing of specific crop inputs or equipment
- Soil characterization to understand soil moisture to inform grower irrigation decision-making
- Soil characterization to understand soil salinity to inform grower field planning
- Orchard floor analysis, through canopy, to understand how much crop has fallen from trees

Global in-season crop yield projection models to inform seed production decision-making

The challenge: Seed producers grow crops to be harvested and sold as seed to growers. A variety of conditions (e.g., drier than normal in the U.S. Midwest, floods in Brazil) can affect seed yield. Seed producers need to accurately understand, in-season, if they are on track to produce enough seeds to sell to their customers, and, if not, they may increase seed supply to manage supply and seed prices for growers.

How EO data might help: EO data (e.g., SAR, weather)—combined with ground-truth data—can be used to model in-season yield projections globally for crops. SAR data are particularly useful in this modeling for their ability to provide insight into where and how much of a specific crop is being grown, crop phenology, Leaf Area Index, and other indicators of future yield. Along with serving as the basis for global models, SAR can help adjust and improve existing models (i.e., one agrochemical company uses Sentinel-1 data to detect ponding, combining this analysis with USGS corn and soy predictive yield maps, which do not account for ponding's negative effect on yield, to improve their U.S. yield projection).

Key data attributes: Global coverage is critical and multiple bands, including L-, S-, C-, and X-band—are preferred and offer different insights across the growing season (e.g., finer bands are important for marking the start of the growing season when crops may only have a few leaves) and across different parameters (e.g., L-band is preferred for crop classification, X-band to detect ponding); but functional models and benefits can be obtained without all bands. Weekly revisit is preferred, although up to 12 to 18 days may be acceptable. Next-day latency is preferred.

SAR-based vegetation indices to inform in-season nitrogen management tools used by growers

The challenge: Multispectral vegetation indices (e.g., NDVI) enable grower decision support tool developers to provide operational recommendations to growers across a range of use cases, including in-season nitrogen fertilizer management. In this use case, decision support tools help growers make decisions based on both on-the-ground data (e.g., crop variety, soil conditions) and EO data (e.g., vegetation indices, weather forecast) to inform when, where, and how much nitrogen to apply. Spatially varying nitrogen application according to crop health and other factors can help farmers maximize yields and profits while protecting the environment. Cloud cover presents significant challenges in satellite-based decision tools. And for some crops (e.g., grapes, apples, pears, kiwis, prunes), multispectral indices are challenging to interpret.

How EO data might help: SAR data have been shown to correlate to Leaf Area Index and other parameters useful for decision support tool developers. SAR's incorporation into existing tools can improve reliability in existing use cases by ensuring recent data are available in the event of cloud cover; improved reliability/assurance of temporal resolution may help drive adoption of these tools. Use of SAR may also expand adoption of satellite-based vegetation indices to new regions (e.g., cloudy) and crops for which multispectral indices are hard to interpret (e.g., apples).

Key data attributes: Temporal resolution and latency are important because growers need recent data to inform fertilizer application decisions. The acceptable revisit rate varies by crop and management practices; weekly data product updates are the longest valued, and down to daily updates would be valued. Spatial resolution of fertilizer applicators are often 10 to 20m, and similar data resolution would be valued; finer resolution would add value down to 3 to 7m.

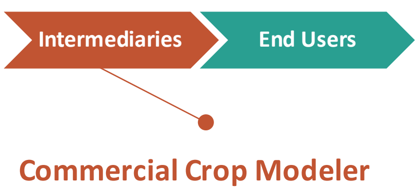
Commercial Crop Modeler at Large Agrochemical Firm

User Community:

Agricultural Field Analysis

Who are they?

These are scientists who bring a combination of agronomic and geospatial experiences and education to their role; they are pragmatic in evaluating new data products and workflows.



Who do they work for?

Within the internal data science team, they split time supporting different internal projects (e.g., seed production team to inform seed pricing, grower decision support tool team to develop crop nitrogen prescription).

> *"Achieving more modern data formats and easier access to ready-to-use products is key for ag-specific use cases. And that requires partnership with industry and NASA."*
>
> —Commercial Crop Modeler, Large Agrochemical Company

Commercial crop modelers evaluate and assimilate large EO and on-the-ground data sets into practical, reliable tools to inform internal or client decision-making.

What decisions are they making (and how) today?

Commercial crop modelers enable internal decisions within their data science team and evaluate new data sources, including SAR data sources. These data sources are for using in models and setting up procedures to download and process data, including geometrically and radiometrically correcting SAR SLC files. Commercially relevant, operational decisions supported for internal clients by their models include the following:

- In-season yield estimates for different crops
- Crop nutrient (e.g., nitrogen) prescription tools
- Understanding of agricultural practices (e.g., crop type, tillage practice) to inform the targeted marketing of agricultural input products and other services
- Monitoring for crop damage (kinetic damage and damage due to ponding) to inform grower response and insurance payouts
- Verification of carbon credits in near real time and more

They may also be involved with commercially relevant R&D projects that are not yet operational.

Do they have experience with EO data?

They have a wealth of experience with EO data, typically having previously completed a PhD related to using EO data for informing agricultural decision-making.

What do they want or care about?

They care about connecting EO data to decisions of real business value. While curious as scientists, they face pressure to weed out academically oriented EO data uses from those that hold promise for bringing real commercial value to their firm. Not only do they consider if EO data can provide insight to a commercially relevant parameter, but also (1) if they can produce a scalable, operational workflow to get that data into the hands of decision-makers in a time frame that retains value, (2) how the data can be transformed into an actionable insight for the end user (e.g., a crop prescription instead of a vegetation index value), and (3) if the value of the insight is significant enough for the end user to adopt it. Adoption will require end user behavior change and investment, either through direct payment or even through investment of time if the data product is free/bundled with other services.

Commercial Crop Modeler at Large Agrochemical Firm

"Daily data feeds are overkill for most farmers. We have already seen this with optical imagery. For 99% of our use cases, daily passes are not worth the cost."

—Commercial Crop Modeler, Large Agrochemical Company

"Value of EO data links to the intrinsic value of the crop (e.g., grapes for wine, corn for silage). EO data and associated workflows may be valuable for higher-cost wine grapes or almonds, but it might not work at all for corn in the Midwest."

—Commercial Crop Modeler, Large Agrochemical Company

"The world's largest wine producer monitors the global grape harvest in 52 locations via Sentinel-1. Is there a bud burst at vineyards in South Africa due to soil moisture? If so, they need to know. We need free data for this kind of extensive monitoring."

—Commercial Crop Modeler, Large Agrochemical Company

"If you ask 1000 farmers what NASA was doing for them, few will know. NASA would be well served to partner with ag companies to help message value with companies already at the farm gate. This can obfuscate the mystery around NASA and reach impact more quickly through scale."

—Commercial Crop Modeler, Large Agrochemical Company

What are their technical needs?

They need low- or no-cost data and data access with attributes specific to the use case of interest. For all data products, they want easier access than the current environment via an API, preferably one enabling access to STAC-compliant, geometrically corrected products that can be manipulated with cropping tools before export. In current workflows, they spend considerable time and internal resources downloading data they do not want (e.g., 100- x 100-km scenes when a 10- x 10-km farm is of interest) and geometrically correcting it in-house. One current user noted they would *"like it if NASA provided"* the geometric correction.

Continuous ground-truth data for soil analysis use cases are needed; efforts to collect or compile such data could improve adoption of soil analysis use cases. In support of insurance actors, modelers noted there is not a current model or threshold for delineating "lodged" and "slightly bent" crops; there is a desire for standardization here.

What would motivate them to use NASA EO data?

They may be motivated to use NASA data in combination with other data sources to improve temporal resolution of their decision tools and benefit from unique NASA data attributes.

What are their adoption barriers for using NASA EO data?

Currently, they work to support operational, commercial use cases. Doing so requires scalable processes and reliable data access. Challenges in data access and unreliable/unclear future data availability could slow or prevent the use of NASA data.

What are they afraid of?

They experience a reality wherein farm management decisions with potential to be informed by EO data today, which require real financial value to drive adoption, are still largely unrealized. They worry this status quo will not change; even with free data the costs associated with processing from low-level products will never enable a scalable service pricing for agricultural sector stakeholders.

What do they NOT care about?

They do not want to think about all the possible use cases; they want to quickly narrow down on those with real commercial value.

Commercial Corn Grower

User Community:

Agricultural Field Analysis

Who are they?

Their family farm has grown significantly in recent decades and now spans over two thousand acres. They draw on years of on-farm experience, family knowledge, and formal education to run their farm.

Who do they work for?

They are self-employed, working to maximize profits for their fields. They work with crop buyers (who may buy rights to their harvest before planting), crop insurers, crop consultants, and seed/equipment distributors to plan farm operations.

Commercial corn growers are focused on hitting crop yield targets for their field this growing season.

What decisions are they making (and how) today?

Commercial growers make over 40 key agronomic decisions every year. Preseason, they focus on planning and preparing their field; they evaluate field conditions (e.g., soil compaction, salinity, and nutrient content) and long-term weather predictions and consider incentive schemes from different seed suppliers to determine which plant hybrid is best for this year. They choose between new hybrids that balance price with various features (e.g., drought resistance) that reduce yield risk and more. When it comes time to plant, they apply fertilizer to their field. They may apply it at variable rates across their field, informed by a crop consultant's variable rate prescription service. This service draws on 5 years of historical yield data and crop models built on satellite and other data to recommend spatially varied rates of application. In-season, they may receive crop monitoring services from the same consultant that alerts them of potential threats to the target yield. For example, if monitoring shows an area of crop that does not emerge at the same time as the rest of the field, they may decide to buy a faster maturing crop variety to replant in-season, improving the chances of meeting their yield target. They monitor moisture, yield, and crop characteristics to inform harvest date and storage until pickup by their buyer.

Do they have experience with EO data?

They have limited to no direct experience with collecting or processing EO data. They know their crop consultant is using satellites now for some of the recommendations they make, such as in their variable rate subscription service.

What do they want or care about?

They want to ensure they manage threats to their yield target efficiently to maximize profit, but their plot is too expansive to lay eyes on regularly. So, they want operational awareness tools to help them manage their field(s).

1. ESG (Environmental, Social, Corporate Governance); CSR (Corporate Social Responsibility)

RTI Innovation Advisors

Commercial Corn Grower

"I use a great farm management program now. It's got all the data I need in one place, so no need to juggle 10 different spreadsheets. My neighbor uses their in-season nitrogen recommendation tool too, but I'm not sure it's worth the cost."

—Representative of Commercial Corn Grower

What are their technical needs?

They need crop consultants or other existing suppliers to incorporate new EO data, crop models, on-the-ground data, and tools into easy-to-use, operational farm management tools. They do not have much time to evaluate new technologies and incorporate them into day-to-day decision-making. Depending on the decision being informed, the underlying data attributes vary significantly, which their suppliers understand. Decisions range from those requiring intraday to weekly data product updates and 10 to 20 m to submeter spatial resolution.

What would motivate them to use NASA EO data?

To convince growers to use NASA data, they need to see a clear return on investment to justify taking the time to adopt tools and practices based on NASA data.

What are their adoption barriers for using NASA EO data?

Pilot projects and endorsements of services by existing, trusted network connections in their community can help drive adoption; however, they have a very low risk tolerance. Before changing their practices, they will want clear, convincing evidence of profitability associated with behavior change. They will want that evidence to be generated from growing conditions like theirs, including soil type, crop variety, weather, and irrigation type. Developing this evidence can be hard and time intensive because data can typically only be gathered and iterated on once per growing season. Even if evidence is developed for EO-based services, growers of silage corn, compared with high-value crops, like wine grapes, have less ability to pay for services because of the lower profit margins.

What are they afraid of?

They are afraid of missing their target yield prediction this growing season. They would rather stick to current, proven practices than adopt new methods that offer minimal benefit and unknown risks.

SDC User Community Profiles

	Property Geohazard Risk Analysis
	Sustainable Forestry
	Agricultural Field Analysis
	O&G Infrastructure Management
	Mineral Exploration & Extraction
	Water Utility Management
	Power Generation and Distribution

User Community:
Oil & Gas Infrastructure Management

Community Overview

The O&G infrastructure management community includes O&G companies engaged in the extraction and transportation of O&G and service providers to whom they may outsource some modeling, analytics, and inspection tasks. This community builds and maintains infrastructure to extract and distribute O&G; key infrastructure includes land-based oils wells, offshore platforms, and pipelines (including gathering, transportation, and distribution pipelines). Companies in this community have a growing interest in leveraging EO data to monitor risks to their infrastructure (e.g., natural hazards, construction near a pipeline) to reduce the costs of on-the-ground monitoring and reduce the potential for and extent of adverse events. For these companies today, EO-based monitoring may be used for monitoring infrastructure in areas of high geotechnical risk, but it is not broadly adopted for continuous monitoring across the length of most assets.

Key User Profiles for SDC

- **Intermediaries**: Technical Lead at SAR-Focused Service Provider
- **End Users**: Product Manger at Pipeline Inspection Service Provider

Key Use Cases for SDC Data Products

- InSAR monitoring of transportation pipelines to reduce geohazard risks
- Ice hazard analysis to inform response to ice floe risk to offshore platforms

Moving Forward for SDC

Although SAR data are already used in this community for monitoring assets in high-risk areas of limited spatial extent (e.g., sections of pipelines near fault lines), there is an opportunity (with NISAR and later SDC data) to expand the use of SAR data to more extensively cover O&G assets (e.g., across the full length of a transportation pipeline). In general, NASA L-band SAR data are seen as key to enabling expanded pipeline monitoring, because EO experts noted it solves key technical limitations (i.e., lack of dual-look geometries over North America, lack of high temporal resolution L-band) of the PoR. Experts noted NASA data will still likely need to be complemented by high-resolution, purchased data for monitoring of high-risk areas though.

NASA has an opportunity to join an existing innovation ecosystem that includes other government agencies engaged in O&G infrastructure management technology development. These agencies include the Department of Energy (DOE) and Department of Transportation (DOT). The DOT's Pipeline and Hazardous Materials Safety Administration's (PHMSA's) annual conference, the PHMSA 2020 R&D forum, identified geotechnical threats, especially at river crossings, as one of the highest areas of concern ripe for pipeline management technology-based improvements. The DOE, and DOT's PHMSA represent potential collaboration partners for NASA because they have existing knowledge of O&G infrastructure management needs and connections with private industry. Without working through these or other existing connections to industry, engagement with NASA data products may be slower and fully reliant on private-sector service providers.

User Community:
Oil & Gas Infrastructure Management

Organizational Assessment

O&G companies are generally well capitalized and early adopters of new technologies that can improve their operations and profitability, although fluctuations in energy prices can lead to significant reduction in investment in new technologies. Some of these companies have significant geotechnical engineering experience in-house, and in some cases, they have remote-sensing experts within their GIS teams. Generally, however, remote-sensing expertise is not common; thus, they look to partner with third-party service providers for EO-based image acquisitions and other EO-based services. In the near term, although these organizations are the primary end users of EO data analysis, they are more likely to partner with external firms to develop infrastructure management monitoring solutions with EO data.

Leading EO-based service providers have extensive (sometimes decades) experience processing radar and optical data for monitoring offshore platform risks, on-field wells and gathering pipelines, and transport pipelines (typically with a spatially limited focus in high-risk areas, such as near fault lines or areas where landslide risk is high). These same EO-based service providers may also support projects for the O&G sector beyond just infrastructure management, including resource extraction use cases (e.g., using InSAR to inform enhanced oil recovery operations). They also support clients in other sectors, such as mining, where geotechnical analysis and activity monitoring via SAR are valued. These firms are the most likely to directly access and process NASA data products in this community. They are likely to evaluate and adopt new NASA data products without significant technical assistance. In addition to EO-based service providers, O&G firms partner with third-party service providers for on-the-ground pipeline inspection and monitoring services. Historically, these organizations use limited to no EO data for pipeline services, although use of both satellite and other EO data is becoming more common; they primarily rely on other inspection and monitoring methods. These companies are curious to learn more about how EO data may complement their existing service offerings. They have limited expertise incorporating EO data into their work.

Data	Intermediaries	End Users
On-the-ground data and inspections are combined with **EO data (e.g., SAR, optical)** to inform a range of decisions. Free, global coverage data from **space agencies** are valued to potentially monitor assets across significant distances affordably; but high-resolution data from **commercial constellations** are leveraged in many cases.	EO-based service providers are sophisticated EO data users who are needed to operationalize EO data for asset owners and on-the-ground inspection service providers. **Technical Leads at SAR-Focused Service Providers** drive delivery of change-detection and InSAR monitoring services that reduce risk of damage to infrastructure and the environment. **Optical-Focused Service Providers** exist as well, offering similar change-detection services and detection of active leaks to pipeline owners.	The primary users are **O&G Asset Owners**, including companies that extract resources (owning gathering pipelines and extraction wells/platforms), transport resources, or distribute them to consumers. EO data from intermediaries may be accessed directly by O&G asset owners or through existing service providers. For example, **Product Managers at Pipeline Inspection Service Providers** may partner to access EO data to triage on-the-ground services. **ESG-oriented Investors** and **Government Regulators** may also use EO data to understand or regulate environmental impacts.
	Profiled in this report	Profiled in this report

1. Resource extraction use cases in the O&G industry are not covered in detail in this report, which instead focuses on infrastructure management use cases. Exclusion of the extraction resources is driven by limited industry feedback that extraction use cases require resolutions expected to be supplied only by commercial SAR providers.

User Community:
Oil & Gas Infrastructure Management

Technical Assessment

Summary: Reliable, simple access to Level 0 and SLC data products is top priority for existing service providers that use SAR data to support O&G companies. These users expect L-band data products with dual-look geometry, weekly repeat, and 10-m resolution to improve and likely expand the use of pipeline monitoring use cases in this community. Across use cases, low-resolution (e.g., 10 m) government data will likely be used in combination with higher temporal and spatial resolution X-band data to achieve monitoring needs.

Current Data Products Used: Satellite EO-based service providers use a range of SAR data sources, X-band (e.g., TerraSAR-X, COSMO-SkyMed, IECEYE, KOMPSAT-5, TanDEM-X), C-band (e.g., Sentinel-1, RADARSAT), and L-band (e.g., ALOS-2). In addition to SAR data sources, commercial RF mapping (e.g., HawkEye 360) and optical data sources are used.

Nonsatellite EO data used include Lidar or optical flown systems, which may be flown monthly, quarterly, or every 1 to 3 years, to assess changes to the pipeline right-of-way and determine where further inspection or work may be needed. Besides regular monitoring with these systems, they may be flown in response to specific events (e.g., after floods or record rainfalls, after other analysis identifies strain/movement on the pipe, after a potential right-of-way issue).

Other data sources, beyond EO data, include free swimming inline inspection tools (known as “smart pigs”), manned inspections, acoustic leak detection tools, data from internal measurement units to map pipelines, and pressure and fiber-optic sensors.

Preferred Data Attributes

Spatial Resolution: Preference is for 3- to 10-m products. For deformation monitoring of smaller areas (e.g., on-field wells and gathering pipelines and change detection), the high-resolution end of this range is preferred. For monitoring long, linear structures, such as O&G pipelines, there is a trade-off between resolution and scene size, which affects the cost of services to the O&G firm. Service providers must weigh this trade-off with their client’s goals and willingness to pay. This trade-off is identified by existing data users as one of the leading reasons why SAR data have not been used more to cover pipelines. The 10-m resolution, complemented by high-resolution data at key areas of interest (e.g., river crossings, where pipelines transition to below or above ground, urban areas), is seen as potentially enabling increased pipeline coverage in the future.

As one private-sector service provider explained, the trade-off is that if they want the pixel resolution that provides enough data points of interest in and around the pipeline, they tend to go towards 3- to 5-m data. But that restricts scene size to ~40- x 40-km, so they may need dozens of stacks of images to monitor a pipeline that’s hundreds of miles long. They noted that if they pursue that option, data buy costs and processing costs become unmanageable, and their clients are not willing to pay for the service. They noted that free data sets can enable more affordable analysis, but they provide less detail on the ground.

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User Community: Oil & Gas Infrastructure Management

Technical Assessment

Preferred Data Attributes (continued)

Temporal Resolution: Users prefer weekly repeat for ~10-m products to enable monitoring of geotechnical threats (e.g., subsidence). They may desire hourly to 1- to 2-day repeat for high spatial resolution products (from 3 m to submeter) depending on the use case; for example, third-party encroachments to a pipeline right-of-way require low precision and resolution but a higher frequency of acquisition. As with the spatial resolution trade-off, use of higher temporal resolution products can increase processing costs, although it is worth the added cost in some cases. Currently, offshore platform monitoring also demands a near daily revisit rate.

Spectral Band: Users desire L-band to improve data for vegetated areas, complementing C- and X-band InSAR observations. Today, the lack of higher spatial and temporal resolution L-band data, as well as the lack of dual -look geometries for Sentinel-1, is seen as a significant barrier to increased adoption of pipeline monitoring in this community in North America. In addition to vegetation penetration, users view L-band as potentially enabling an expansion of pipeline monitoring work in the arctic beyond the "shoulder seasons"—a 4-month summer period when snow cover does not negatively affect the ability to provide SAR-based pipeline monitoring; users view NISAR data as an opportunity to better understand the utility of L-band data in this area.

Polarization: Users in this community said single-pol data are usually acceptable, but dual-pol data would be nice to have across use cases. One existing user expressed doubt that polarimetry could reliably detect hydrocarbon spills over land, although they noted it could, of course, detect these over water. Dual- or quad-pol may be required for relatively rare use cases related to ice hazards analysis, where ice can pose risks to offshore oil platforms. In these use cases, users value SAR polarimetry to help characterize ice to determine if it can be broken up by icebreakers or if the platform must be moved, at a cost of hundreds of millions of dollars. Dual- or quad-pol data are also desired for soil moisture-based analyses of pipeline risks.

As one current data user explained, hydrocarbons like gas and oil do not have a unique dielectric constant that will easily enable detection of spills over land. They noted that methane-observing satellites may be better at leak detection (though not prevention) from gas pipelines and that optical leak detection of oil leaks may be ideal; though InSAR and SAR polarimetry may be able to provide insight into these leaks depending on the cause and effect of the leak observable in the surrounding environment.

Latency: Daily latency is acceptable. If possible, SLC data are desired hours after collection, with accurate orbit vectors.

Coverage Area: Global coverage is preferred. Users see dual-look, high-resolution L-band data coverage as particularly valuable for expanding demand for services over the European Union (EU) and North America, but monitoring efforts are substantially global.

User Community:
Oil & Gas Infrastructure Management

Technical Assessment

Preferred Data Attributes (continued)

Data Formats: For SAR data, users prefer Level 0 and SLC products. Current data users noted that easier and free (or cheaper) access to low-level SAR data products would improve the ability to deliver commercial monitoring services, including for new data acquisitions and archived data (e.g., the RADARSAT 1 and 2 archive).

Other: These users desire dual geometries; they see the lack of these dual geometries in North America from Sentinel-1 as a barrier to increased adoption of pipeline monitoring.

It would be a benefit if Sentinel-1 and NISAR/SDC shared the same orbit to provide the same acquisition geometry.

For liquid and gas pipelines, geotechnical threats (e.g., subsidence) are seen as requiring minimum decimeter if not centimeter-level precision.

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User Community: Oil & Gas Infrastructure Management

Use Cases

Within this community, use cases for SDC data products exist. Use cases with **bold** text have additional detail.

- **InSAR monitoring of transportation pipelines to reduce geohazard risks**
- SAR-based activity monitoring to detect right-of-way encroachment and vector on-the-ground response
- **Ice hazard analysis to inform response to ice floe risk to offshore platforms**
- Platform subsidence monitoring for offshore O&G platforms
- Surface uplift monitoring to inform underground gas storage safety

InSAR monitoring of transportation pipelines to reduce geohazard risks

The challenge: O&G pipelines are expansive, with transportation pipelines spanning 2.6 million miles in the United States alone.[1] Monitoring across the length of these assets can be challenging, and improved solutions are particularly desired in remote areas where cost of monitoring hardware can be significant and often requires solar power and satellite modems, and be at risk for theft or vandalism. But continuous monitoring is needed to extend asset life, conserve budgets, and avoid potential environmental risks.

risks to pipeline health before they cause damage, InSAR monitoring can enable on-the-ground teams to respond to and mitigate risks. **How EO data might help:** InSAR monitoring can provide O&G pipeline owners with expansive, reliable monitoring of geohazard risks across the length of their pipelines. By pinpointing

Key data attributes: Dual-look geometries and the availability of L-band are ideal for enabling monitoring of the pipeline across its length, including in areas on slopes and under cover of vegetation; 10-m, weekly repeat data will likely be valued in this use case. But, importantly, these resolutions may not be sufficient in high-risk areas (e.g., near fault lines, where pipelines transition to below or above ground, urban areas); existing data users expect to balance data costs and resolution to create solutions with various data sources that meet the needs of their clients. These solutions will likely include higher temporal and spatial resolution data for high-risk areas. If data buys and processing costs made it feasible, users prefer 1- to 2-day repeat rate and 3- to 5-m data across pipeline assets.

Ice hazard analysis to inform response to ice floe risk to offshore platforms

The challenge: Offshore platforms are constructed at significant costs, typically exceeding hundreds of millions of dollars; the cost of moving the platforms after construction can be similarly expensive. Large ice floes can pose a potential risk to these platforms. To protect the value of their investment, platform owners may need to assess ice floes to determine if an ice floe can be broken up by hired icebreakers or if a platform must be moved.

How EO data might help: SAR data can be used to complement existing ice maps, potentially improving ice thickness assessment to inform whether the ice can be broken up by icebreakers. Better understanding of the risk posed by a given floe can increase confidence in decision-making and potentially reduce costs of maintaining offshore assets.

Key data attributes: This use case is less common than others in this section, and key data attributes are not clear. One user described that L-band and X-band will likely complement C-band data in monitoring ice and be useful in helping assess ice thickness. L-band may not be as good at detecting young ice, but it may give less noise from the water surface when mapping older ice floes. Users said quad-pol L-band was potentially less useful than quad-pol C-band at discriminating ice type, but co-pol L-band could potentially offer the most benefit for improved signal-to-noise ratio (S/N).

1. U.S. Department of Transportation. (2018, November 6). General pipeline FAQs. https://www.phmsa.dot.gov/faqs/general-pipeline-faqs

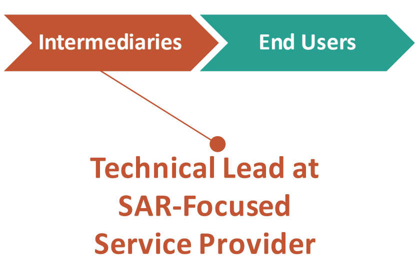
Technical Lead at SAR-Focused Service Provider

User Community:

O&G Infrastructure Management

Who are they?

SAR experts with years of experience developing and exploiting InSAR techniques to provide geotechnical support to clients in the O&G, mining, and other sectors.



Who do they work for?

They manage the SAR services team in the delivery of monitoring services for their O&G industry clients.

> *"Regularity and reliability of the acquisitions is my top priority for future missions. To build and grow a commercial SAR-based services businesses, you have to be able to rely on the data sources you are using."*
>
> —Technical Lead, SAR-Focused Service Provider

SAR-based pipeline and other monitoring services may help O&G firms reduce risk of damage to infrastructure and the environment.

What decisions are they making (and how) today?

Decisions they support through their analyses span both extraction/production site infrastructure monitoring, which is more concentrated in one area, and transport pipeline monitoring, covering thin assets that can span hundreds of miles. On O&G fields, InSAR helps answer their clients' questions about risk to pipes and wellbores shearing or kinking, especially around fault lines and dense on-field pipeline networks. For transport pipelines, InSAR monitoring can help inform proactive maintenance by the client to reduce chances of an adverse event occurring, and SAR-based right-of-way encroachment monitoring can act as a vector for on-the-ground response teams to ensure damage (e.g., from construction) to the pipeline is avoided. For offshore platforms, InSAR can monitor subsidence, and SAR polarimetry can support analysis of the lowest cost response to an ice floe (e.g., is thickness such that it can be broken up by icebreakers, or does the platform need to be moved).

Do they have experience with EO data?

They have extensive experience with EO data, particularly SAR data.

What do they want or care about?

Their top priority is regular, reliable acquisition and access to low-level SAR data products. They are excited about L-band because of its vegetation penetration and additional look geometries over North America, but specific data attributes are secondary in priority for them compared with reliable data access.

Technical Lead at SAR-Focused Service Provider

> *"Oil and gas companies are 100-year businesses. Our clients ask us—'what happens after the 7-year mission?' Will there be data after that?' They're not sure what to do with the uncertainty of future data."*
>
> —Technical Lead, SAR-Focused Service Provider

> *"Beyond new data, general increase in the level of awareness about the potential of SAR data in this industry would be beneficial for market adoption by itself."*
>
> —Technical Lead, SAR-Focused Service Provider

> *"Free L-band from NISAR may make monitoring of long-distance Canadian arctic pipelines easier—or possible in some cases."*
>
> —Technical Lead, SAR-Focused Service Provider

What are their technical needs?

They rely on a combination of government and commercial data sources to meet their clients' needs on most projects, so they do not need one satellite constellation to meet all of their needs. In terms of data attributes, needs vary by use case (see previous section for more detail). Specific priority technical needs, considering currently available data, include high-resolution (i.e., 10 m) L-band data and dual-look geometries over North America.

What would motivate them to use NASA EO data?

They will use NISAR data when they arrive, and they will likely use SDC data in the future. High-resolution, free L-band data with dual-look geometries over assets of interest will likely lead to use in pipeline monitoring use cases, especially in vegetated areas. Simple, reliable data access will improve their user experience with NASA EO data and increase the likelihood and volume of use. Long-term clarity about data continuity beyond current missions will also play a role in motivating them to build services based on NASA data compared with other data. When analysis results are comparable, they will likely choose data sets with clear and long continuity into the future.

What are their adoption barriers for using NASA EO data?

These users have no significant adoption barriers for their use of NASA Level 0 and SLC SAR products in the future, unless regularly accessing these products is not easy.

What are they afraid of?

N/A

What do they NOT care about?

They do not care about sourcing all their data from one place. They are in the business of, and excel at, combining data sources to best serve their clients' project-specific needs. NASA data do not need to meet all their needs to be useful in improving their services.

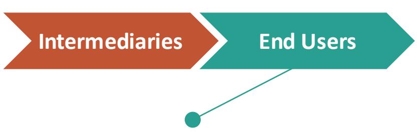
Product Manager at Pipeline Inspection Service Provider

User Community:

O&G Infrastructure Management

Who are they?

Pipeline experts with on-the-ground experience conducting pipeline inspections and other services to support pipeline management. They are eager to understand how new data sources or techniques can help them meet their clients' needs.



Product Manager at Pipeline Inspection Service Provider

Who do they work for?

They provide sensors and services to both O&G firms and utilities that own water/wastewater pipelines.

"Geotechnical threats, especially at river crossings, were identified as one of the highest need areas in our industry for improved technology solutions at the 2020 federal pipeline regulator R&D forum."

—Product Manager, Pipeline Inspection Service Provider

Pipeline experts work with both O&G and utility clients to enable the cost-effective, safe management of pipeline assets.

What decisions are they making (and how) today?

In support of their clients, they provide inspection services and monitoring that inform the best approaches for extending the life of pipeline assets and conserving budgets. Their services help prevent failures due to erosion, scour, landslides, and third-party encroachments. Before inspections, users review historical records of pipeline alignment, failure history, and hydraulic analysis of pipeline flow and pressure to orient field activities. Inspection tools include inline devices (e.g., smart pigs) and manned inspections. Acoustic leak detection tools, internal closed-circuit television, and data from inertial measurement units can help map pipelines. Tools can be located from above ground and can record GPS points to help identify the location of the pipeline point where on-the-ground response is warranted. They may partner externally for EO-based service providers, including with satellite-based service providers to help identify pipeline risks or with other service providers to fly imaging systems (e.g., drones, helicopters, light aircraft) along pipeline rights-of-way (annually, twice a year, or more often) to identify incursions along the rights-of-way (e.g., construction activities along the right-of-way).

Do they have experience with EO data?

They have limited experience with EO data. They have purchased EO data and services before, but in-house expertise processing EO data is not common.

What do they want or care about?

In their experience, it is more cost-effective to inspect, repair, and actively manage existing pipeline assets than to replace them. But pipeline assets are expansive, so they care about identifying the best tools/data to help prioritize which pipes or locations to evaluate first. They would like to be able to eliminate dependency on expensive monitoring hardware on the right-of-way, which often requires solar power and satellite modems, especially in remote areas, or regions where theft and vandalism are likely.

Right-of-way is defined by DOT PHMSA as "the property, or easement, that pipeline operators secure to install and maintain transmission pipelines. Operators generally obtain ROW by purchasing the property, by mutual negotiated agreement with a landowner, or through court-ordered condemnation procedures."

Product Manager at Pipeline Inspection Service Provider

"We are intrigued by EO-based monitoring at scale, but our customers want a high level of confidence before they consider replacing existing methods. For now, we only use EO-based inspections in niche situations."

—Product Manager,
Pipeline Inspection Service Provider

"10m products sound big given the narrow nature of transport pipelines. But maybe 10m data can serve as the basis of triggering on-the-ground or more precise EO follow-up."

—Product Manager,
Pipeline Inspection Service Provider

What are their technical needs?

For geotechnical threats to liquid and gas pipelines, these users recognize that gradient changes of interest at localized areas on slopes can be caused by ground movement much deeper than the pipe is buried. The fact that these movements result in only small changes on the surface leads them to want at a minimum decimeter- if not centimeter-level precision. They can accept weekly to 1- to 2-month updates for this geotechnical monitoring. For right-of-way encroachments (e.g., construction activity), they require lower precision and resolution but higher frequency of data; ideally 4 to 12 hours but at lower spatial resolution. To prevent illegal taps of pipelines used for theft via tunneling or small pothole excavations, they need both high-resolution and frequency of data.

What would motivate them to use NASA EO data?

Solutions that affordably improve their clients' pipeline management processes would draw them to use NASA data; although in the short term, they would likely need to partner with third-party experts in EO processing to use NASA data. Solutions for areas of high concern, such as river crossings, would be particularly valued; these are already areas recognized by the PHMSA as high priority for improved monitoring solutions.

What are their adoption barriers for using NASA EO data?

They have little experience with EO data processing, although they do have experiencing partnering with EO-based service providers to incorporate EO data into their client services. A key barrier for them is justifying the cost of high enough resolution data-based services. They need services built from NASA or other EO data to (1) be affordable to them, considering the cost of data buys (when applicable) and processing, and (2) show significant value for their clients, compared with alternative methods, before adoption.

What are they afraid of?

They are afraid of losing market share to competitors with new, more efficient methods (including using other EO data or more effective data analysis approaches). They are interested in conducting joint research and partnering to mitigate this risk.

RTI Innovation Advisors

SDC User Community Profiles

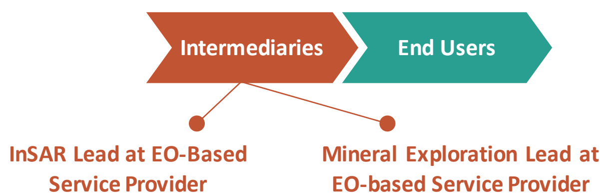
- Property Geohazard Risk Analysis
- Sustainable Forestry
- Agricultural Field Analysis
- O&G Infrastructure Management
- Mineral Exploration & Extraction
- Water Utility Management
- Power Generation and Distribution

User Community:
Mineral Exploration and Extraction

Community Overview

The mineral exploration and extraction community includes mine operators, their technology and service providers, their insurers, commodities and environmental, social, and governance (ESG)-oriented investors, and government regulators. In this community, EO data (including SAR data) are already used extensively to ensure safe and efficient identification and extraction of minerals that fuel the global supply chain. Experienced users of EO data in this community are eager for additional EO data that will enable improved existing and potentially new services within the community.

Selected User Profiles for SDC



Potential Use Cases for SDC Data Products

- InSAR for stability monitoring of tailings dams to ensure safe operations
- InSAR for slope stability monitoring at operational pit mines to ensure safe operations

Moving Forward for SDC

Mining-sector clients are a leading private-sector user of EO and SAR data; they are increasingly a focus for SAR-based service providers. These providers use InSAR to manage both wide area issues and events in detail so that they can make timely decisions related to both safety and operations. They want to be able to provide high-resolution, more frequent InSAR-based services to their clients in this and other sectors, so they highly value InSAR-oriented satellites.

For mine site use cases, NASA L-band data will be highly valued in this community for vegetation penetration and because it makes for easier phase unwrapping in InSAR workflows over mine sites where large deformations occur. Beyond high temporal resolution L-band data, this community would highly value more regularly updated DEM products; they currently derive DEM measurements from SAR because the DEM update rate they need is faster than what available products support.

For mineral exploration use cases, SAR is currently seen primarily as a complement to multispectral data. There are opportunities to expand SAR use in mineral exploration if research can prove out less developed SAR use cases (e.g., use of multipol SAR data for compositional mapping, differentiating rock types as a function of their head capacity). Intermediaries in this community are interested in new SAR use cases, but they may need the to be de-risked through demonstration in the peer-reviewed literature to help make adoption feasible.

User Community: Mineral Exploration and Extraction

Organizational Assessment

Mining companies place a high priority on continued reliable monitoring, both from EO and on-the-ground sources, to reduce operational risks. They rely primarily on third-party service providers to leverage EO data, which they combine in-house with on-the-ground data and processes. Insurance companies and ESG-oriented financial institutions are more reactive consumers of EO data in this community, purchasing EO-based services to understand the potential causes and damage extent of adverse events after they have occurred. These investigations may be used to adjudicate insurance claims or inform buy/sell decisions associated with ESG targets. As a result of recent adverse events in the mining industry (e.g., the Brumadinho dam disaster), mine asset owners and operators are becoming increasingly aware of the need for monitoring solutions that reduce risks associated with their tailings dams, tailings piles, and pit mines. This need has driven a recent increase in demand for InSAR-based services because mining companies see a clear financial incentive to reduce their liability and to optimize operations.

Intermediary EO service providers in this community are mature users of EO data. Mineral scouting, stability monitoring, and activity monitoring service providers have and will continue to develop workflows to support services sold to mine asset owners and operators—the leading end users in this community. Insurance companies and ESG-oriented financial institutions also buy services from the same providers, especially to support investigations following an adverse event (e.g., tailings dam failure). Leading EO-based service providers have extensive, sometimes decades of, experience processing SAR data for mineral extraction use cases. They are highly sophisticated users of SAR and other EO data. When use case–specific data attribute needs are met, they will be able to evaluate and incorporate new SAR data sets into their workflows with limited technical assistance. Most of these service providers serve clients in the mining sector and other sectors where SAR data are valued for geotechnical analysis (e.g., the O&G industry, as well as civil infrastructure). Mineral exploration–focused service providers have extensive EO data processing experience, but historically SAR data have been less relevant than optical data for their use cases; they have potential to increase their use of SAR data if key use cases with new data products are shown to be feasible and valuable

Data	Intermediaries	End Users
On-the-ground data are combined with **EO data (e.g., SAR, optical)** to inform a range of decisions. Free, data with global coverage from **space agencies** are valued to drive consistency in methods and when low resolution is acceptable, but **commercial constellations** are leveraged when high temporal or spatial resolution data are needed.	EO-based service providers are sophisticated EO data users who are needed to operationalize EO data for use by mining companies. **InSAR-Leads at EO-Based Service Providers** are SAR experts leading efforts to support stability monitoring use cases of tailings piles, tailings dams, and mine walls. **Mineral Exploration Leads at EO-Based Service Provider** use a wide range of EO (mainly optical) and other data to enable mineral exploration activities.	Use of EO data across users in this community has grown in recent years. Users include **Mine Owner and Operator** staff (e.g., tailings engineers who integrate on-the-ground and third party–provided EO-based data into geotechnical analyses of tailings dams and storage facilities) but also include the **Mine Operators' Insurers**, **Commodities Traders ESG-oriented Investors**, and **Government Regulators**

Profiled in this report

User Community: Mineral Exploration and Extraction

Technical Assessment

Summary: Weekly updates of 10-m SLC products can support stability monitoring use cases of mine walls, tailings piles, and tailings dams, although high temporal and spatial resolutions products are valued to improve these and support other use cases as well. Mineral exploration use cases 30-m global coverage products of multiband, multipol data, temporal resolution, and latency are low priorities for them.

Current Data Products Used: Commercial EO-based service providers use a wide variety of government and commercial SAR data sources to support stability and activity monitoring use cases. For stability monitoring, data sources include Sentinel-1, TerraSAR-X, COSMO-SkyMed, ALOS-2, ICEYE, and RADARSAT. High-resolution commercial SAR satellites, commercial RF mapping (e.g., HawkEye 360), and some government satellites are also used for SAR-based activity monitoring. Across satellite EO analyses, DEM products, including Airbus's high-resolution DEM, are used. On-the-ground radar systems (e.g., IDS GeoRadar IBIS Series) are also used for their fast repeat rate.

In mineral exploration, multispectral data are the primary type of EO data used today. Sources include ASTER, Sentinel-2, WorldView-3, and other data; ground-truth spectral data are also used. Radar satellites are beginning to be used more often for scouting in areas with significant forest cover where optical data do not penetrate. Sentinel-1 has been used most often, but Terra-SAR-X, COSMO-SkyMed, and other higher-resolution data have been used as well. Beyond EO data products, geophysical (e.g., magnetometry, gravity, radiometric), geochemical (e.g., lithogeochemical, soil samples, lake sediment), and geomorphology (e.g., regolith, geological maps) are all used too.

Preferred Data Attributes

Spatial Resolution: For many stability monitoring use cases 10-m SLC products are useful, although high-resolution data (1 to 3 m) are valued for targeted monitoring of key locations. Low-resolution products, like 30-m deformation products, may be valued and usable to support mining use cases, but users see them as unlikely to replace use of SLC-based processing for high-resolution outputs. For mineral exploration, high-resolution (30-m) products are acceptable for most use cases.

Temporal Resolution: Users view weekly data products as acceptable for many stability monitoring use cases; these services may integrate with mine operators' weekly to monthly updates to internal map products. Down to daily revisit use case needs are primarily high spatial resolution and seen as well served by commercial satellite data providers. Notably, temporal resolution of DEMs is also important for stability monitoring use cases, and service providers face challenges today given that DEMs are typically much older than SAR data. They have adopted DEM workflows to incorporate SAR data into existing DEMs, and they would value DEM products with higher temporal resolution (i.e., monthly updates).

User Community: Mineral Exploration and Extraction

Technical Assessment

Preferred Data Attributes (continued)

Spectral Band: EO-based service providers expect to use many SAR bands in their work with mining-sector clients, selecting the most affordable data source that meets the resolution requirements of the given use case. For pit mine stability monitoring, L-band is particularly valued because of the severe deformations occurring on site; phase unwrapping procedures are simpler with L-band in these use cases because of the longer wavelength. In mine activity monitoring, this capability enables monitoring of assets obscured by forests (e.g., a copper mine in the Amazon).

Mineral exploration use cases for SAR may benefit from multiple bands (e.g., C- and L-band) to help differentiate surface mineralization. L-band may also be able to assist with differentiating rock types as a function of their head capacity, although this use case is less developed.

Polarization: For mine site monitoring, users prefer dual-pol data and may see some benefit to quad-pol data.

For mineral exploration, multiple polarizations, ideally quad-pol data, may be valued for surface compositional mapping. One user noted that this use case remains largely theoretical though and has not yet been demonstrated.

Latency: For mine site monitoring, latency is a high priority data attribute; and next-day latency is acceptable for most users. Users noted that most of their use cases are safety critical (e.g., monitoring of an unstable rockface, monitoring of a tailings dam), so they desire reliable access to low-latency data products to reduce the potential for negative outcomes and build trust in the use of SAR data. As one current user explained, *"time to access data once the collects are captured is a real struggle with ESA data. The delay between capture to availability in catalog for us to download slows down our ability to respond to demand or customer interest. If that could be streamlined, it would be wonderful."*

Latency is a low priority for mineral exploration.

Coverage Area: For mine site monitoring, users need only data over the mine sites; these sites are globally distributed but typically spanning 5 to 25 km^2 in area.

For mineral exploration use cases, users value global coverage overland. For some EO data products, mineral exploration–focused EO data users experience gaps in coverage above 60-degree latitudes because of orbits of government satellites. They noted in these areas that commercial data providers do not routinely collect data, and if they do, the data are often useless because of the snow cover.

Data Formats: Users in this community prefer SLC files today for InSAR and other SAR-based use cases. Current data users believe high-level data products, including coherence maps, weekly interferograms, and weekly deformation maps, could be valuable, but they may have limited use in the community if they do not meet the spatial resolution needs of the existing use cases.

Other: One EO-based service provider indicated that long, historical time-series data are valued for work with insurance companies, because they may be interested in analyzing historical deformation at a site.

User Community: Mineral Exploration and Extraction

Technical Assessment

Example Workflows: Workflows vary by organization and use cases, and examples are provided to illustrate ways existing data products are used in this community.

Mineral exploration example workflow: *"Analytics data [are] already [orthorectified] and corrected to surface reflectance and may also be composited (we have proprietary bare earth composites we have generated from full archives of data, i.e., ASTER). So, workflows are typically basemap generation, masking (water, vegetation, snow, ice, some cloud and cloud shadow if needed), data product generation using multispectral techniques such as RGBs, ratio and mineral indices. Then we will use ground-truth and other supporting data to go to mineral mapping (using supervised classification) if applicable. Depending on the scale, can also do a machine learning study; then finally interpretation steps, product generation, and delivery."*

Ongoing stability monitoring example workflow: *"(1) Receive and discuss client request, (2) review current catalog of resources across all available devices, (3) share with client and configure acquisition and time to deliver (e.g., 4, 7, 11 or 12, 24-day differentials), (4) push data through the data processing blender, (5) share initial outputs and tune to deliver data in the preferred scenario/format, and (6) revisit and harmonize with expected outcomes."*

ESG company post-event investigation workflow: *"In an event-driven scenario, something occurs on site, and operators or ESG companies look for insight into extents and impact of something like a tailings dam failure (water levels, river pollution, vegetation degradation). We pull SLCs from our different sources and convert as needed to run through our different workflows and provide results in preferred outputs to customer. Update/repeat as needed."*

User Community: Mineral Exploration and Extraction

Use Cases

Within this community, a range of use cases exists that may benefit from SDC data products. Many of these use cases are of interest for both active/operational mines and closed mines because mine operators may have liability after a mine site closure. Use cases with **bold** text have additional detail.

- **InSAR for stability monitoring of tailings dams to ensure safe operations**
- InSAR for slope stability monitoring of large mineral ore and tailings piles to ensure safe operations
- **InSAR for slope stability monitoring at operational/active pit mines to ensure safe operations**
- Historical InSAR analysis of tailings dam failure for post-event insurance investigations
- SAR-based activity monitoring of closed mine sites to inform triaging of ground teams to respond if needed
- SAR-based analysis of damage extent post-tailings dam failure for ESG/finance stakeholders
- SAR-based estimation of dry vegetation (to supplement NDVI, which captures healthy/green vegetation) to support vegetation masking tools in mineral exploration
- SAR-based differentiation of rock types as a function of their head capacity in mineral exploration
- Topographic and structural data extraction from SAR amplitude data to provide supporting data in mineral extraction workflows

InSAR for stability monitoring of tailings dams to ensure safe operations

The challenge: Tailings dams store by-products of mining operations, and their failure can lead to loss of life for mine workers and surrounding communities, detrimental environmental and health impacts, and financial losses for mine operators and their insurers.

How EO data might help: Surface deformation and dam fractures can precede eventual dam failure. EO data, particularly InSAR, can help spot indicators of failure risk before failures occur, enabling on-the-ground response to further assess and mitigate risks that could contribute to an eventual failure.

Key data attributes: Reliability in data capture and access is critical to enable safety-critical monitoring operations. Users see the 10- to 12-day repeat rate of 10- to 20-m SLC products as useful, but a significant benefit could be derived from a higher temporal frequency (as often as to 1 to 7 days) and higher spatial resolution (down to 1 to 3 m).

InSAR for slope stability monitoring of operational pit mines to ensure safe operations

The challenge: Ensuring pit mine slope stability is critical to the safe and profitable operation of mines. Although design plays a critical role in future slope stability, unidentified geological structures, weather conditions, seismic activity, and other factors can lead to slope failure, necessitating continuous monitoring of stability.

How EO data might help: InSAR can serve as a complement to on-the-ground data, providing precise understanding of slope conditions that can integrate into safety management workflows. Through use of InSAR monitoring, mine operators may be able to detect some precursors to slope failure before they are visible to on-the-ground monitoring equipment.

Key data attributes: Reliability in data capture and access is critical to enable safety-critical monitoring operations. Users noted that a weekly repeat rate of 10-m SLC products is acceptable, but higher temporal frequency (as often as to 1 to 7 days) and higher spatial resolution (down to 1 to 3 m) are preferred. Many SAR bands are useful, but L-band is valued because of the severe deformations possible in pit mining; phase unwrapping is easier with L-band's longer wavelength.

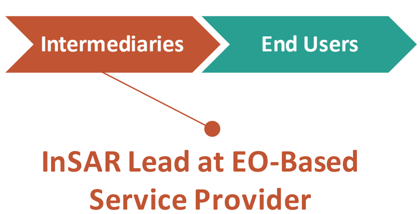
InSAR Lead at EO-Based Service Provider

User Community:

Mineral Exploration and Extraction

Who are they?

They are InSAR experts with years of experience developing and exploiting InSAR techniques to provide geotechnical support to clients in the mining, O&G, and other sectors.



Who do they work for?

They manage the InSAR services team in the delivery of stability monitoring services for clients in the mining sector, a client base that has grown significantly in the last 5 years.

> *"In the mining industry, they have problems we can't solve without L-band."*
>
> —InSAR Lead, EO-Based Service Provider

InSAR service leads deliver stability monitoring services to mine operators to help reduce the risk of adverse events at active and closed mine sites.

What decisions are they making (and how) today?

Across the decisions they support, they are leveraging in-house InSAR workflows that begin with SLC files from commercial and government data providers. Decisions they support through their InSAR analyses at active and closed mines include stability monitoring of tailings dams and tailings piles. Their clients use these analyses, together with on-the-ground data, to ensure precursors to potential adverse events related to the tailings facilities are identified early on and mitigated. These users also support slope stability monitoring in pit mines, where deformation is particularly severe; here again, their services are used in conjunction with on-the-ground processes to ensure safe operation of the mine.

Do they have experience with EO data?

They have extensive experience with EO data, particularly SAR data.

What do they want or care about?

They are excited for NASA L-band data to arrive in the form of NISAR because they see L-band as critical to their mining-sector use cases. They want to be able to provide higher resolution, more frequent InSAR-based services to their clients in this sector (and others), so they highly value InSAR-oriented satellites. They recognize their need to integrate the best available satellite products from both government and commercial sources to serve their clients' needs; in sourcing government products, they want a better, faster way to download and integrate products into their workflows, which they note support operational, safety-critical decision-making. They also care about access to long time-series data.

InSAR-lead at EO-based Service Provider

"We have problems accessing data from free SAR sources today. It takes a long time to download, and it is not ideal how it's cataloged. And there can be safety-critical needs for an unstable rockface or tailings dam monitoring. Smoothing the delivery pipeline would be a massive benefit for us."

—InSAR Lead,
EO-Based Service Provider

"Our clients appreciate the red-yellow-green, simple to understand reports we can provide them to help monitor critical assets."

—InSAR Lead,
EO-Based Service Provider

What are their technical needs?

In constraining their InSAR analyses, they rely on DEMs that are not regularly updated, and they are forced to employ their own DEM workflows to modify these products to better constrain their InSAR analyses. They would value more regularly updated DEM products. They would also like to benefit from multiple-look geometries over the United States. Their technical resolution needs vary by use cases. Preference is for 10-m products available every 2 to 4 days, but significant value would be derived from weekly products; they expect such products would not change their need for high-resolution products in many use cases.

What would motivate them to use NASA EO data?

They will use NISAR data when they arrive, and they will likely use SDC data in the future. High-resolution, free L-band data over their mine sites of interest will be the primary draw for them to use NASA data. Simple data access via an API will significantly improve their user experience with NASA SAR data.

What are their adoption barriers for using NASA EO data?

They face no significant adoption barriers in using NASA SAR SLC products in the future. They may face a barrier for using high-level SAR products if they are too coarse in terms of spatial resolution; high-resolution, high-level products will increase the likelihood of use, although they recognize SLC files will likely continue to be preferred.

What are they afraid of?

They are afraid that clients relying on them for safety-critical insights will not receive those insights in time because of the challenges in the data access pipeline and that adoption of SAR-based services will remain low because of unclear continuity of future missions.

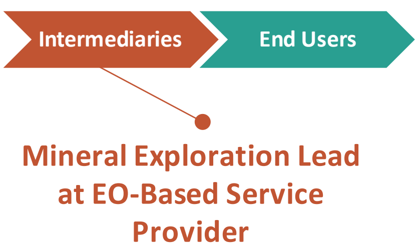
Mineral Exploration Lead at EO-Based Service Provider

User Community:

Mineral Exploration and Extraction

Who are they?

They are EO and geology experts with years of experience using multispectral and other products to search for evidence of mineralization.



Who do they work for?

They work primarily with major mining firms to provide remote-sensing support in exploration of gold, copper, nickel, and other commodities.

> *"Optical data work really well for most mining exploration needs, so we would only use SAR when optical cannot work."*
>
> —Mineral Exploration Lead, EO-Based Service Provider

Mineral exploration service providers combine EO and other data into insights that accelerate their clients' mineral exploration activities.

What decisions are they making (and how) today?

They are leading client engagements, helping to manage their internal team to meet their clients' needs. On a typical project, they leverage internal EO product databases and processes in conjunction with ground-truth and other supporting data to create mineral maps for the client. Currently, they rely primarily on optical EO data sources, but ground-truth spectral data and radar satellite data are also used with geophysical and geochemical data.

Internal decisions they make related to EO data center around how new products or workflows could improve internally maintained product databases and processes. Related to SAR, they support exploration of techniques for SAR-based quantification of dry vegetation (to complement optical products in vegetation masking), L-band data to assist in differentiating rock types as a function of their head capacity, and multipol SAR data for compositional mapping.

Do they have experience with EO data?

They have extensive experience with EO data, particularly optical data but also radar data.

What do they want or care about?

A significant aspect of how they provide value to their clients is the ability to offer analyses with global coverage; although they value high-resolution products, global coverage is their priority. They are interested in the potential for new SAR use cases (e.g., use of multipol SAR data for compositional mapping), but they recognize many of these are not yet developed or demonstrated today. To help make adoption feasible, they want new SAR or other EO data use cases for mineral exploration to be de-risked through demonstration in the peer-reviewed literature. Outside of SAR data, they care about continued support for existing optical products and hope to obtain high-resolution thermal data in the future.

RTI Innovation Advisors

Mineral Exploration Lead at EO-Based Service Provider

"The most value for me is having data everywhere overland; that's better than a 'spotlight' with higher resolution in some places."

—Mineral Exploration Lead, EO-Based Service Provider

What are their technical needs?

They would benefit from high-temporal resolution topography products, because they currently extract radar amplitude data to improve mineral extraction workflows. They value L-band's ability to enable analysis where optical data cannot, as a result of vegetation cover, and its ability to provide insight into rock head capacity. They want increased access to, and improved resolution of, L-band data.

What would motivate them to use NASA EO data?

They are likely to use NISAR data when they arrive because they want better access to L-band data. If NASA offers global coverage data products, they are likely to consider their utility in mineral exploration workflows.

What are their adoption barriers for using NASA EO data?

If NASA products are limited in geographic coverage area, they could have low utility across mineral exploration use cases. For emerging or hypothetical applications of EO data for mineral exploration, there may be limited or no adoption before use cases are demonstrated in the peer-reviewed literature.

SDC User Community Profiles

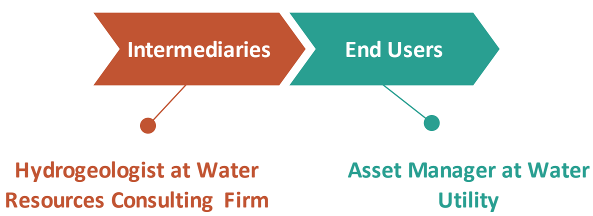
	Property Geohazard Risk Analysis
	Sustainable Forestry
	Agricultural Field Analysis
	O&G Infrastructure Management
	Mineral Exploration & Extraction
	Water Utility Management
	Power Generation and Distribution

User Community: Water Utility Management

Community Overview

The water utility management community works to ensure water and wastewater services are available to residential and commercial customers. The community includes public utilities; product and service providers (e.g., design/construction service providers; treatment equipment vendors, pipeline inspection service providers, water resources consultants); and local, state, and federal government organizations providing enabling resources and regulating water-related challenges. Across the community, EO data can enable improved management of distributed infrastructure (e.g., nonrevenue water leak detection to triage maintenance), forecasting and management of droughts (e.g., for irrigation districts), and water quality events, and more. Excepting some service providers, the community has little experience processing EO data but does benefit from products and services provided by federal government partners and private-sector service providers. As infrastructure continues to age and the climate continues to change, EO data may grow in importance to this community in the coming decade.

Selected User Profiles for SDC



Potential Use Cases for SDC Data Products

Soil moisture analysis to optimize drinking water pipeline leak detection and maintenance

InSAR for GPS data to inform groundwater pumping limits set by subsidence districts

Moving Forward for SDC

As with other user communities, SDC has an opportunity to either lead or participate in innovation ecosystems and partnerships that also involve other federal, state, and local government organizations. End users in this community typically rely on a combination of federal government (e.g., NOAA, USGS) EO data products and private-sector service providers to incorporate EO data into their work; this will likely remain the case in future. Drought forecasting and management is a leading area of concern for them and represents a key opportunity for NASA to engage them. Beyond specific data product attributes, they want EO leaders such as NASA to introduce frameworks and enable sharing of methods that can result in less repetitive data processing across organizations in the water resources community. As one water resources consultant explained, they have the technical experience to merge Landsat, Sentinel-2, InSAR, and other data to generate evapotranspiration (ET), snow, and irrigated agriculture time-series data now, but the processing of the data in-house limits where it can be applied (because of the internal processing resources required). They see more standard products as enabling the growth in use of EO data for water resources management. Recognizing that even though water resources consultants use InSAR time-series data now in support of their groundwater withdrawal regulator clients, they find InSAR software costs limiting to their efforts. SDC should consider options for addressing this challenge to enable more widespread use of InSAR, including further engagement with water resources consultants to determine if/how high-level NASA data products may reduce their need for in-house InSAR processing.

RTI Innovation Advisors

User Community: Water Utility Management

Organizational Assessment

Needs of public water utilities that could be addressed through EO data are diverse, ranging from drought forecasting/management to water quality monitoring and alerts to pipeline/dam infrastructure monitoring. Utilities benefit from EO data today by accessing products provided by NOAA and the USGS and sometimes from EO-based services offered through service providers. Water utilities want to learn more about how NASA data products may help enable their work, particularly those facing increasing challenges related to sea level rise, water quality, and drought. But they are likely to continue to depend on government and private-sector partners to process and provide insights from EO data in the future.

Water resources consulting firms support water utilities, regulators, and other stakeholders in their management of water resources. They have some expertise processing EO data in-house today (e.g., deriving ET from Landsat data), and they want to better understand the next generation of NASA data products to potentially incorporate into their workflows. They represent a key pathway through which NASA data products can affect water resources management. They have limited experience with SAR data; one firm noted that they needed to work with a local university to obtain interferograms for a recent project focused on groundwater withdrawal.

Infrastructure monitoring and inspection-focused service providers help water utilities manage their distributed infrastructure (e.g., potable water pipes, wastewater pipelines/sewers). They provide equipment and services to enable a better understanding of this infrastructure to effect more efficient and proactive maintenance. These organizations historically use limited to no EO data in their services, although use of satellite and other EO data is becoming more common; some firms are focused on only EO-based services. These companies are curious to learn more about how EO data may complement their existing service offerings. They represent an opportunity to help grow the use of EO data in monitoring water utility infrastructure. They currently learn about EO data services through direct engagement with startups developing water utility–targeted services and reports/webinars from leading water industry market intelligence platforms.

Data	Intermediaries	End Users
EO data in this community are often accessed **from federal and state government** partners who provide **high-level data products** and **research institute/university partners for InSAR data.** Some users in the community may access low-level products, such as **Landsat NDVI** and surface temperatures to derive ET and water consumption estimates, and **SAR SLC files** to enable soil moisture–based leak detection.	intermediaries Include **Hydrogeologists at Water Resources Consulting Firms** with years of experience in groundwater, quantitative hydrogeology, and groundwater modeling. They have the technical experience to merge Landsat, Sentinel-2, InSAR, and other data to generate ET, snow, and irrigated agriculture time-series data now; but they are interested in high-level products to obviate this work internally. **Sar-focused Service Providers** also offer leak detection and dam/levee monitoring solutions to this community.	End users include **Managers of Water Utility Assets,** working to manage drinking water and sewage pipe condition assessments, repairs/rehabilitations of these pipes, and hydraulic modeling. Others include **Hydrologists**, **Meteorologists**, **Geologists**, **Groundwater And Waste Specialists**, and **Program Managers** at utilities that analyze data to predict impacts of high- and low-water events and make decisions on raising/lowering reservoirs. In some cases, these users may blur the lines between "intermediaries" and "end users" in this framework; most really on high-level products or third-party intermediaries.
	Profiled in this report	Profiled in this report

User Community: Water Utility Management

Technical Assessment

Summary: The heterogeneity of this community means desired data attributes vary significantly across users and use cases of interest; 1-m spatial resolution to watershed-level data is desired at repeat rates ranging from intraday to seasonal. EO-focused service providers work from SLC files, but most users work from high-level data products. Users value products related to soil moisture, subsidence, and SWE-related data. For water/wastewater pipeline inspection, users have a strong desire for high temporal resolution L-band quad-pol data to enable the use case.

Current Data Products Used: A wide range of data products is used for water resources management, including various databases compiled by state and federal agencies with groundwater and surface water levels; weather and climate-related data from NOAA; Landsat, flows, and groundwater levels from USGS; GRACE data (primarily for areas with very large aquifers); spatial maps of land crop data from USDA; GPS and InSAR data for groundwater withdrawal monitoring; U.S. Drought Monitor products; dam and stream gauges; and snow core samples taken by local organizations to augment federal government products.

For infrastructure monitoring, EO-based service providers use C-band data (e.g., Sentinel-1) as SLC files for InSAR monitoring of dams and levees and L-band data (e.g., ALOS-2, SAOCOM) for polarimetry-based water/wastewater pipeline leak detection. Non-EO data sources for infrastructure monitoring/inspection service providers include free swimming inline inspection tools (known as smart pigs), manned inspections, acoustic leak detection tools, data from internal measurement units (to map pipelines), and pressure and fiber-optic sensors.

Preferred Data Attributes

Spatial Resolution: Needs vary by use case. For EO-based dam, levee, and pipeline monitoring, users want 3-m data and view 10-m data as the upper limit for useful data.

For water resources management, users prefer 1- to 5-m data to inform agricultural water use monitoring, but Landsat 30-m data are seen as useful for watershed-level analysis. One user noted regarding SWE that the *"ability to measure snowpack and SWE accurately and over a large area, like quantifying water in snow storage in the Sierra Nevada, would be really valuable for planning purposes for somewhere like the California Central Valley."*

For dam-level and stream gauge sensors, as well as SWE, users are not sure what EO data resolution would be required to reliably replace or meaningfully augment their existing on-the-ground sensors.

User Community:
Water Utility Management

Technical Assessment

Preferred Data Attributes (continued)

Temporal Resolution: Depending on the use case, users value data informing seasonal, weekly, and daily decision-making.

For snowpack data, users view monthly data products as the minimum, with a 1- to 2-week repeat rate required in drought conditions. For water gauging above a dam, typically data are acceptable every few days to once a week, but in flood conditions it is important to receive data every 12 hours.

EO data users monitoring infrastructure value down to daily data in some cases, and 14- to 16-day repeat is seen as the worst-case usable data. One current user remarked that for 10-m data, 12-day repeat rate may be ideal; they explained that 10-m data are not providing safety-critical information but rather acting to augment on-dam sensors, so the maximum repeat rate is not needed. They noted that in their current practice they may only use 12-day data (even when 6-day data are available) because the processing is not justified by the relatively low value to their clients.

Spectral Band: L-band is highly valued for polarimetry-based soil moisture analysis, which is used to help detect water and wastewater pipeline leaks for water utilities. Some service providers also use InSAR-based monitoring to support pipeline leak detection; for these users, C-band or X-band may be preferred because L-band offers minimal benefits (with most water pipes running near the road and not under vegetation cover—unlike O&G pipelines).

L-band is seen as offering benefits for InSAR-based dam and levee stability monitoring because these can experience significant vegetation and soil cover. One current user notes they would ideally use multiple bands (e.g., L, C, and X) together to improve their dam monitoring.

Polarization: Users view quad-pol data as critical for polarimetry-based soil moisture analysis for water/wastewater pipeline leak detection. One current data user focused on this use case stressed that *"we hope dual-pol will become a legacy polarization by 2028, and that quad-pol will become the default standard. We hope NASA will be a leader on the technology front, enabling quad-pol and other specifications and letting private sector companies continue to uncover and develop innovative ways to exploit that data commercially."*

Latency: Daily latency is example for EO data products. For safety-critical dam level monitoring (e.g., during flood conditions), users noted it is critical to receive intraday data.

Coverage Area: Users prefer global coverage. Currently, the lack of dual-look geometries over North America is seen as limiting for the expansion of dam and levee deformation monitoring services. InSAR products will be particularly valued in areas facing challenges related to subsidence; in these regions, InSAR can complement spatially limited ground-based GPS monitoring of groundwater withdrawals.

User Community:
Water Utility Management

Technical Assessment

Preferred Data Attributes (continued)

Data Formats: For EO-based, SAR-focused service providers, Stripmap SLC products are preferred today. One existing user noted that they would be interested in considering use of NASA-provided interferograms in the future, but they would always want SLCs to be available; they noted one potential benefit of a third-party, free interferogram would be the ability to provide faster updates to their clients without adding processing costs.

For water resources consultants who use SAR data less often, interferogram products or lower cost InSAR processing software would help make InSAR and other SAR analyses more accessible.

As one user noted, *"we see an open-source software gap in the use of SAR data. If we want to do InSAR processing in-house, the available commercial software is super expensive. More than $50k–70k per license. There is a strong initiative by the EU to provide access to software tools for EU members, but there is a firewall for parties outside of the EU. We could have that access for our EU branches, but we see that as a limitation for us. We have many easily accessible tools that work anywhere in the world; but not for SAR. There could be an effort so that all that data could be integrated in an open-source manner for everyone in the world, for the benefit of all. For now, it's frustrating to find the right tool to access InSAR data."*

Other: For existing SAR data users, dual-look geometries—for InSAR-based dam/levee/pipeline management—over North America and reliable low-latency data access are top priorities.

One user noted *"we would not mind paying for data if we have to; the key for us is business reliability of data delivery. Can we get better or priority access if we pay NASA? We'll use the [NISAR] data either way. But we prioritize reliability."*

User Community: Water Utility Management

Use Cases

Within this community, use cases for SDC data products exist. Use cases with **bold** text have additional detail.

- InSAR monitoring for supplementing on-the-ground data for dam/levee management
- InSAR monitoring for supplementing or optimizing on-the-ground pipe condition assessments
- **InSAR for supplementing GPS data to inform groundwater pumping limits set by subsidence districts**
- SAR for construction detection in flood zone downstream of dam to inform reassessment of dam hazard classification
- **Soil moisture analysis to optimize drinking water pipeline leak detection and maintenance**
- Soil moisture analysis to inform drought management by state agencies, irrigation districts, and utilities
- Snow extent and SWE data to inform drought prediction by state agencies, irrigation districts, and utilities
- Surface water extent to inform dam flood risk level

InSAR for GPS data to inform groundwater pumping limits set by subsidence districts

The challenge: In many communities, groundwater is a critical resource, and careful management of this resource is needed to meet current and future water supply needs while minimizing land subsidence impacts on infrastructure, flooding, private property, and groundwater storage capacity. In some regions (e.g., Houston/Galveston, TX), subsidence districts help monitor and regulate groundwater's use. But on-the-ground monitoring methods are spatially limited, leading to an incomplete understanding of groundwater withdrawal–linked risks.

How EO data might help: SAR-based subsidence data can work alongside on-the-ground data (e.g., co-located GPS and extensometer data) to fill in existing data gaps in the district between the spatially limited on-the-ground sensors; these additional data can improve decision-making related to groundwater pumping to manage subsidence. The SAR-based data can also help inform where to place additional on-the-ground sensors.

Key data attributes: Ideal data attributes required to support this use case are unclear to existing users, because use of SAR data for this use case is seen as emerging and not yet well understood. Typically, subsidence data are used to inform long-term (e.g., annual) targets for groundwater use, and subsidence data are not expected to be needed frequently to enable this use. One user at a water resources consulting firm suggested at least monthly updates to data would be ideal to enabling continuous monitoring; latency of this data would be low priority, and the highest spatial resolution possible is desired.

Soil moisture analysis to optimize drinking water pipeline leak detection and maintenance

The challenge: Utility water pipeline networks are distributed across the utility's service area, and leaks within the network are challenging to detect across this expansive area. Often, leaks are not detected until they are reported by customers. When not identified and addressed quickly, leaks can lead to economic challenges for the utility in the form of potential damage and contribution to nonrevenue water totals.

How EO data might help: SAR-based polarimetry can help identify where leaks may be occurring across the pipeline network, helping triage on-the-ground crews to further investigate and address leaks. This approach has the potential to increase efficiency and detect leaks earlier, before they are reported by customers. As a SAR service provider noted, utility crews may investigate 10 potential leak spots per day and identify one leak; SAR data can help triage spots for investigations and result in their finding six leaks per day across 10 spots—a sixfold increase in efficiency.

Key data attributes: Quad-pol L-band data are highly desired to enable this use case. Preference is for 3-m spatial resolution, and 10 m is seen as the worst-case useful data. Daily revisit is preferred, and 14 to 16 days is seen as the worst-case useful data.

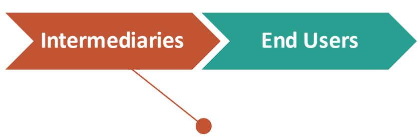
Hydrogeologist at Water Resources Consulting Firm

User Community:

Water Utility Management

Who are they?

They are hydrogeologists with years of experience in groundwater, quantitative hydrogeology, and groundwater modeling.



Hydrogeologist at Water Resources Consulting Firm

Who do they work for?

Clients are diverse, including water utilities, regulators (e.g., subsidence districts), irrigation districts, and state and federal irrigation project teams.

> *"For us, continuity is a key data attribute. I would feel hesitant to introduce data in a workflow that might not be generated in the future."*
>
> —Hydrogeologist, Water Resources Consulting Firm

Water resources consultants use EO data to provide water resources and water supply consulting services to their clients.

What decisions are they making (and how) today?

For watershed-level analysis, they measure and analyze the entire hydrologic cycle to inform water-related planning and management by public utilities and irrigation districts and state or federal irrigation projects. These clients end up affecting individual water users (e.g., farmers, homeowners) through their management decisions. To support this work, hydrogeologists use a range of regional water-related data products, including from federal and state agencies, to understand groundwater and surface water levels. These products may be used directly or further processed (e.g., Landsat NDVI and surface temperatures are used for ET and water consumption estimates). To support subsidence district regulators, they combine GPS groundwater sensors with InSAR data to monitor groundwater withdrawals, enabling the regulator to determine limits to set around groundwater pumping. In this use case, GPS sensors are seen as providing the highest confidence in accuracy and temporal resolution, but they are spatially limited. InSAR helps fill gaps where GPS sensors cannot be installed and helps informs where they should be installed.

Do they have experience with EO data?

They have significant experience processing EO data. But they have limited experience with SAR compared with other data.

What do they want or care about?

They want to maintain and improve their client services. To do this, they are interested in (1) accessing better data products that improve their analysis; (2) accessing new, standard products (e.g., interferograms, OpenET), which replace existing processes and enable them to spend more time on other project issues; and (3) ensuring the future continuity of critical products (e.g., the continuity of the temperature band from Landsat is seen as critical for estimating regional water usage). Beyond specific data product attributes, they want EO leaders like NASA to introduce frameworks and enable sharing of methods that can result in less repetitive data processing across organizations in the water resources community. One user explained they have the technical experience to merge Landsat, Sentinel-2, InSAR, and other data to generate ET, snow, and irrigated agriculture time-series data now, but the processing of the data in-house limits where it can be applied today (as a result of the internal processing resources required). They see more standard products as enabling the growth in use of EO data for water resources management.

Hydrogeologist at Water Resources Consulting Firm

"We see an open-source software gap in the use of SAR data. If we want to do InSAR processing in-house, the available commercial software is super expensive."

—Hydrogeologist, Water Resources Consulting Firm

"Regarding open-source vs. proprietary data, many of our contracts are for public agencies that require that we provide all source data used to generate the result. So, we are often unable to use proprietary data even if it would help improve our work. And that is for contractual, not financial reasons."

—Hydrogeologist, Water Resources Consulting Firm

What are their technical needs?

Needs for specific data attributes vary by use case (e.g., 30-m Landsat data are seen as useful for watershed-level analysis, but 1- to 5-m data would be preferred to inform agricultural water use monitoring). Across their work, high-priority technical needs include the following:

- Improving the ability to measure snowpack and SWE over a larger area (e.g., quantifying water in snow storage in the Sierra Nevada) to inform irrigation district planning (e.g., in the California Central Valley).
- Improving temporal resolution of water quality data to inform water utilities managing water quality risks, enabling them to notify customers or switch water sources as needed in real time.
- Higher temporal resolution ET data to enable more frequent quantification of the water balance to inform irrigation-related work during the growing season; one hydrogeologist mentioned they are excited for OpenET to provide real-time, regional consumptive use data, because they currently internally derive ET from Landsat.
- Having low-cost access to SAR processing software or access to standard high-level products to obviate its need. SAR is noted to be anomalously difficult across remote-sensing data sources to process economically, and this is seen as limiting its use in water resources management.

What would motivate them to use NASA EO data?

They are currently using, and will continue to use, NASA data products. New products that improve their analysis—either through enabling more precise measurements, more frequent updates, or simpler workflows—have potential to drive increased use.

What are their adoption barriers for using NASA EO data?

The cost of SAR processing software is a barrier to use of SAR data.

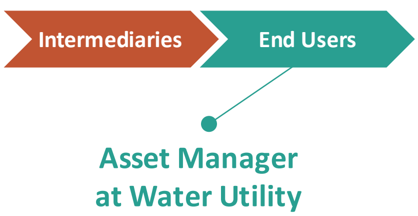
Asset Manager at Water Utility

User Community:

Water Utility Management

Who are they?

They are professional engineers with background in environmental engineering and years of experience managing water/wastewater infrastructure projects.



Who do they work for?

Along with their colleagues, they work for the community in which they live. They may report to a leadership team that is elected by the community.

"One of our strategic goals is to continuously reduce nonrevenue water. If satellite data can enhance our ability to do that, we are interested in learning more."

—Asset Manager, Water Utility

Asset managers ensure reliable access to water and wastewater services in their community through efficient management of distributed infrastructure.

What decisions are they making (and how) today?

They manage the utility's asset management program, which includes drinking water and sewage pipe condition assessments, repairs/rehabilitations of these pipes, and hydraulic modeling. To triage their condition assessment and repair efforts, they develop and rely on their asset management plan, which may be informed by historical data, internal GIS data, customer feedback, hydraulic modeling outputs, third-party inspection services, and other data. They may also support other programs, including those related to water and wastewater treatment infrastructure operations and water supply challenges (including drought and water quality risk management).

Do they have experience with EO data?

They typically have no experience with EO data. They rely on their service providers to provide them with processed readouts to enable their decisions.

What do they want or care about?

They want to efficiently monitor and maintain assets across the vast area covered by their water and wastewater infrastructure, but they have limited financial resources. So, they are interested in cost-effective ways to work more efficiently. They are particularly interested in reducing nonrevenue water (water that leaves the utility's treatment process but never reaches the customer), which can pose a financial challenge for the utility when it occurs as a result of leaks, faulty metering, or theft.

Asset Manager at Water Utility

"Today, some utility O&M crews investigate 10 spots a day and find 1 leak. If our SAR-based algorithm has a 60% chance of finding a leak, we can increase their efficiency by 6x. It doesn't need to be perfectly accurate, like in some science applications, to deliver huge value to utilities."

—Technical Lead,
EO-Based Service Provider

"I had one water utility as a client that was very concerned about seismic events and their large diameter pipelines. Some pipelines are segmented (bell and spigot joints), and ground movement can cause the joints to open-up. Liquefaction and landslides are of concern because they can sheer off pipeline appurtenances when the concrete vault that houses the appurtenance slides away."

—Product Manager,
Pipeline Inspection Service Provider

What are their technical needs?

They need data that can improve their operations, including making detection of challenges more accurate/reliable, lower cost, and faster (e.g., alerts for problems before regular inspection identifies them). For monitoring infrastructure, data needs are limited to the operating area of the utility, but for flood management use cases, watershed-scale data may be of use. With limited familiarity or use of high-level EO data products, asset managers need support understanding how and when to leverage high-level EO data products; and they will rely on third-parties to process, create, and help them interpret those products from low-level data.

What would motivate them to use NASA EO data?

Utility asset managers would consider using NASA EO data (typically through an intermediary because they have limited experience with EO data) (1) if it were available in a format that is affordable and accessible in their day-to-day work and (2) if they see a clear benefit of using the data (e.g., if the benefits of using EO data to reduce nonrevenue water exceeds the costs of accessing and using EO data for thus purpose). For some utilities, increasingly aging infrastructure, climate change, and unique geological challenges could drive them to adopt NASA or other EO data products earlier. For example, utilities in regions with more seismic activity may have more interest than most organizations in products that relate to geohazards. Utilities more heavily affected by climate change (e.g., rising sea level's effect on stormwater management systems, groundwater withdrawal linked to subsidence impacts on pipes) may have more interest in understanding these changes in the context of their management plans.

What are their adoption barriers for using NASA EO data?

They have little familiarity with EO data and limited budgets.

SDC User Community Profiles

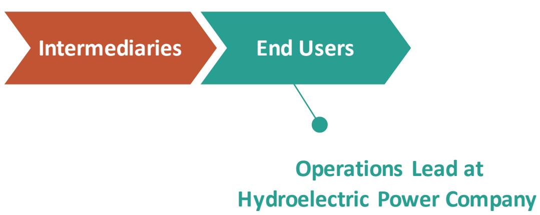
- Property Geohazard Risk Analysis
- Sustainable Forestry
- Agricultural Field Analysis
- O&G Infrastructure Management
- Mineral Exploration & Extraction
- Water Utility Management
- Power Generation and Distribution

User Community:
Power Generation and Distribution

Community Overview

This community includes people and organizations that manage power generation and distribution: utilities (publicly, investor, and cooperative owned) that generate and distribute energy to residential and commercial users; power suppliers; and their product vendors, service providers, and regulators. This community is highly regulated and must comply with Federal Energy Regulatory Commission (FERC) and Environmental Protection Agency (EPA) regulations, as well as state and local public utility requirements, to ensure they appropriately manage risks to the communities they serve. To meet regulatory requirements, manage other risks, and optimize power generation, utilities already use various EO data products, often through collaboration with external service providers with EO expertise. With new and improving EO data products, changes in the U.S. energy landscape (e.g., increasing prevalence of solar energy), and climate change (e.g., increasing risks related to drought and fire hazards), this community offers opportunities for increasing the use of EO data.

Selected User Profiles for SDC



Potential Use Cases for SDC Data Products

Improved snow extent and SWE data to inform efficient, sustainable hydropower operations

SAR-based detection of power line risks (e.g., vegetation growth, dead trees, construction activity) to vector on-the-ground response

Moving Forward for SDC

The power and generation distribution community, which includes the creation and supply of power, is a significant global industry, and one that can greatly benefit from using EO data to understand problems and opportunities, make decisions about associated priorities and strategies, and execute tactical actions and reactions. There are opportunities for SDC related to this community; however, because utilities likely connect to much of the data from NASA's designated observables (DO), SDC should connect to cross-DO efforts with this community. In other words, in reflecting on the value or priority of EO data, SDC is unlikely the appropriate lead for this community. Most end users are more interested in weather, surface biology, and water observations from NASA missions. The exception to this may be SWE data, for which SDC has a clear potential benefit for hydropower generation use cases.

This community typically learns about new technologies through their network of service providers and publications/events from power-focused research institutes (e.g., Electric Power Research Institute) and agencies (e.g., DOE); thus, leveraging the existing innovation ecosystem will help NASA avoid recreating relationships and channels that can be leveraged.

RTI Innovation Advisors

User Community: Power Generation and Distribution

Organizational Assessment

Electric utilities are the leading end user of EO data in this community. Large, investor-owned companies serve most U.S. consumers and represent a key path to impact for NASA EO data; of the almost 3,000 electric utilities in the United States, investor-owned companies comprise only 6% but service 72% of U.S. customers. For managers in this community, EO and on-the-ground data are important for power generation (e.g., optimizing hydropower flows, complying with nuclear power regulations) and distribution (e.g., reducing fire risk damage and liabilities).

Utilities employ science specialists, including hydrologists, meteorologists, geologists, groundwater and waste specialists, and data integrators, to analyze EO and other data across their business today. These specialists are typically on staff and have experience assimilating high-level data products (e.g., NOAA River Forecast Center model outputs) into their workflows. Large utilities also often rely on private-sector service providers with expertise in remote sensing to capture (e.g., drone flights to inspect power lines), process, and assimilate EO data products into their decision-making.

Climate change has heightened utilities' awareness of risks related to water; various water-related use cases may represent opportunities for NASA to provide value to utilities. Drought forecasting and response are of particular concern for power generation (e.g., water is used to generate electricity through hydroelectric systems), distribution (e.g., low soil moisture can be correlated with fire risk), and waste management (e.g., overflow of waste holding ponds due to extreme weather events can lead to environmental damage). Beyond managing water-related risks, EO data also may offer opportunities to reduce operating costs (e.g., replacing on-the-ground sensors, triaging manual inspections).

Utilities desire to maintain good relations with their communities and be seen as good environmental stewards. They are open to understanding how EO data might help maintain these relations and help improve operational efficiency. They typically learn about new technologies through their network of service providers and publications/events from power-focused research institutes (e.g., Electric Power Research Institute) and agencies (e.g., DOE).

Data

Data are collected from on-the-ground **reservoir-level sensors**, **real-time river and dam sensors**, and **evaporation pans** from both internally operated sensors and state and federal government (e.g., USGS) partners. Other data sources include **NOAA's National Center for Environmental Prediction** (including the Climate Prediction Center and weather forecasts), the **U.S. Drought Monitor**, **USDA's SNOTEL** data, and **NASA Soil Moisture Active Passive** (**SMAP**) data. **Drone data** may also inform power line asset monitoring.

Intermediaries

This community has the least experience with SAR data of all the communities profiled. Some users include **Water Resources Consultants** (e.g., modeling drought risks), **EO-Focused Start-ups** (e.g., integrating SAR and drone data for power line monitoring), and **Drone-Focused Service Providers** (e.g., providing inspections for power line monitoring). The community does use some high-level data products like the Flood Early Warning System (FEWS) and the water forecast portal. Contractors are used to build forecast models and provide usable information.

End Users

Operations Leads at Hydroelectric Power Companies manage economic and environmental factors in coordinating operations across generation facilities; they value snow, precipitation, and surface and groundwater data in their work. Other users include **Dam Safety Leads** (e.g., monitoring dam stability), **Groundwater and Waste Specialists** (e.g., protecting coal combustion residual sites from overflow), and **Operations Leads for Power Distribution** (e.g., being aware of and resolving risks to distribution assets).

Profiled in this report

User Community:
Power Generation and Distribution

Technical Assessment

Summary: This community's use of EO data is driven by water-related use cases. To address these use cases, users value various water observations, including surface water, soil moisture, groundwater, weather, and snow data, along with other data (e.g., land cover) that constrain models related to water risk. They use these data to understand the current state and conduct analyses to predict future states. They rely on multiple data sources from internally operated sensors and state/federal government partners. Beyond hydrology-related observations, utilities may be interested in less developed SDC applications.

Current Data Products Used: Data products used from external sources include the U.S. Drought Monitor, USDA (SNOTEL data), NOAA (including weather data, regional River Forecast Center data, the Climate Prediction Center data, and the National Center for Environmental Prediction data), NASA (SMAP data), and USGS (state well sensor-based groundwater data and stream flows). Drone data may also inform power line asset monitoring.

Internally, they also source data from evaporation pans, water-level sensors (on reservoirs, lakes, and dams), snow core samples taken from their reservoirs, and internal flow data (e.g., flow that left their facilities that day).

Preferred Data Attributes

Spatial Resolution: Generally, these users desire high-resolution data, but end users did not identify specific resolution needs for specific use cases. Observations of interest to the community include those at the watershed scale (e.g., drought, groundwater recharge) and smaller scales (e.g., detecting vegetation encroachment on power lines). One user stated if more 10- to 100-m EO data were available, it would likely increase their number of applications for EO data.

Temporal Resolution: Time-series data are important. They desire daily, seasonal, yearly, and decadal historical data. And they prefer at least monthly, but preferably biweekly, observations to supplement or replace internal SWE data.

Spectral Bands: Users interviewed did not specify preferences for a SAR spectral band.

Polarization: Although users did not identify any specific preference for SAR polarizations, they desire soil moisture products from or enabled by NASA.

Latency: For applications requiring daily or weekly data, such as reservoir levels and stream flows, latency is critical in enabling a timely understanding of risks; these data contribute to week-scale forecasting. Drought data typically contribute to 60-day or seasonal forecasting.

User Community:
Power Generation and Distribution

Technical Assessment

Coverage Area: Users of SNOTEL data noted that it does not currently provide data at all altitudes of interest; lower altitudes are not typically included. These users desire SWE data across the watershed to reduce the need to make qualitative assumptions from SNOTEL data regarding snowpack at lower altitudes.

Data Formats: Users want data that are importable or downloadable in appropriate formats so they can easily use the data in a wide variety of programs and platforms. They are less likely to use low-level SAR data products.

Other: These users want an improved understanding of historical snow depth data to help them site solar power resources. And one solar power–focused user noted data that indicate the likely snow melt time could inform the decision to go clear snow off panels or wait for it to melt.

Users would like to detect power transmission threats (e.g., vegetation growth, tree fall risks, unauthorized construction activities); typically, these threats are addressed through drones or other inspection methods. If satellite data can make threat detection simpler, it may be of interest for this use case.

User Community: Power Generation and Distribution

Use Cases

Within this community, use cases for SDC data products exist. Use cases with **bold** text have additional detail.

- **Improved snow extent and SWE data to inform efficient, sustainable hydropower operations**
- **SAR-based detection of power line risks (e.g., vegetation growth, dead trees, construction activity) to vector on-the-ground response**
- Surface water extent to support understanding of stream flows to inform efficient, sustainable hydropower operations
- Surface water extent to inform dam spillover risk analysis and on-the-ground response
- Soil moisture, biomass, and land cover inputs to wildfire risk analysis to triage inspections of power line risks

Improved snow extent and SWE data to inform efficient, sustainable hydropower operations

The challenge: Operations teams at hydropower generators balance economic and environmental (e.g., water availability) factors to optimize generation across resources. They need to accurately understand available water resources to ensure they do not overdraw their reservoirs. Currently, they use SNOTEL data, but they face challenges with its limited coverage (e.g., at lower latitudes); they gather most of their own additional snow core samples and make qualitative changes to SNOTEL data to meet their snow data needs.

How EO data might help: SAR-based snow extent and SWE can provide them a more complete and accurate understanding of their water resources. With these data in hand, they will improve their efficiency and confidence in balancing a range of data factors in their operations. Users may expect to benefit from enhanced SWE data sources through accessing regional NOAA river forecast centers' models or accessing low-level data products directly.

Key data attributes: Data products that expand SWE estimates to lower altitudes will solve an existing challenge for many SWE users. If SWE can be generated at high enough spatial resolution and penetration depth, it may be able to meaningfully augment or even replace on-the-ground snow core samples. Users want to be confident in their understanding of basins and require multiple SWE data points across each reservoir they rely on. They desire data updates every 2 weeks, but up to 4-week repeat data are acceptable.

SAR-based detection of power line risks (e.g., vegetation growth, dead trees, construction activity) to vector on-the-ground response

The challenge: Power distribution networks are vast, and detecting risks to power lines early is critical to enable an on-the-ground response before adverse events occur. These events can lead to increased utility costs and potential damage to private property. Risks posed to power lines are diverse and include ingrowth from vegetation, dead trees near power lines (which may fall onto them in the future), and construction activities that threaten the lines. Understanding these risks has historically required on-the-ground inspections.

How EO data might help: If EO data of appropriate attributes and accessibility exist, power distribution risks may be easier to detect and address early on before adverse events occur. Optical or SAR-based change detection may enable identification of vegetation ingrowth and construction activity risks, and hyperspectral or other data may provide insight into live/dead status of trees.

How EO data might help: To provide meaningful insight into risks, users need high-resolution data; it is unlikely 10-m data can play anything other than a supporting role in this use case. Data <1 to 5 m are likely needed to detect risks, and nonsatellite EO observations or commercial satellites may be best positioned to serve this use case's needs. These users desire highest repeat rate insights, down to daily, but longer repeat-rate data may still be of value (especially if it is playing a supporting role only).

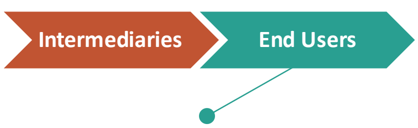
Operations Lead at Hydroelectric Power Company

User Community:

Power Utility Management

Who are they?

They are hydrologists by training with years of experience supporting energy generation workflows. They oversee balancing economic and environmental (e.g., water availability) factors to optimize generation across the utility's generation resources.



Operations Lead at Hydroelectric Power Company

Who do they work for?

Along with their colleagues, they work to safely and reliability generate electricity for the population of consumers and companies in their service area.

"Snow water equivalent data is a huge resource for us. We rely heavily on SNOTEL data to forecast our water supply for the next year."

—Operations Lead, Hydroelectric Power Company

Operations leads manage economic and environmental factors in coordinating operations across generation facilities.

What decisions are they making (and how) today?

They consider economic and environmental data to coordinate and maximize the efficiency of power generation across multiple hydropower facilities. To inform decision-making, users collect data into a Flood Early Warning System (FEWS) database that organizes and manages data inputs; then they use models to forecast flow at various time scales. Using monthly internal SWE data, they monitor how far they can draw on reservoirs to help ensure they are only drawn down as far as they can be replenished. Using real-time river gauges, lake elevation gauges, groundwater monitoring wells, calculated flow discharges from their facilities, and forecast data from the NOAA river forecast centers, they plan their weekly/daily discharges to maximize their ability to respond to system changes.

Do they have experience with EO data?

They do not have significant experience processing EO data. So, they need high-level data products that can be incorporated into their internally generated flow forecast data in order to use EO data. They look to third-party forecasts, like the NOAA river forecast center's river system models, to incorporate the best available flow, precipitation, snowmelt, and drought data into their models.

What do they want or care about?

These users want to improve their flow forecast data to enable more accurate planning of their reservoir management and more accurate forecasting of power generation.

RTI Innovation Advisors

Operations Lead at Hydroelectric Power Utility

"SNOTEL might only give us great data at higher altitudes, but SNOTELs don't see that warm weather lost snow at lower elevations. So, we sometimes have to make qualitative estimations of what the impact of things have been at lower elevations."

—Operations Lead, Hydroelectric Power Company

"Any improvements in Earth observations would be great to work on. However, maybe our wish list is not big enough because we don't know what is possible."

—Operations Lead, Hydroelectric Power Company

"Sometimes there may be data available that we are not aware of, or we don't know where to get it."

—Operations Lead, Hydroelectric Power Company

What are their technical needs?

They care about and are generally interested in improvements to their data across daily, weekly, and seasonal time scales. They are interested in improvements to SWE data, and they face challenges with its availability at only specific elevation levels. They also rely on indirect soil moisture assumptions in their hydrology inflow forecasts, and they would prefer to have more frequent (e.g., weekly) data to better understand infiltration and runoff. They are interested in better understanding aquifer discharge and recharge—at least a 3- to 4-month timescale; they think better resolution snowpack data, better long-term weather forecasts, and other data could help them understand these rates.

What would motivate them to use NASA EO data?

They would consider using NASA data if it (1) were simple to find, (2) were easy to import/download in appropriate formats to be incorporated into their models, and (3) offered improved accuracy in their work (either by providing more accurate data, providing data more often, or providing data they do not have access to today).

What are their adoption barriers for using NASA EO data?

It has been challenging for them in the past to understand what NASA data products exist and how to access them; they say a clearer inventory of NASA data products would help them with this issue.

Sections

Across user communities, users indicated SDC observables are of interest for a range of use cases.

Deformation data

- In the O&G, mining, and water utility communities, deformation data can enable monitoring of risks to distributed infrastructure (e.g., pipelines, dams, levees) that are otherwise challenging to monitor. SDC data could serve to augment high-resolution SAR, other EO, and on-the-ground data in these use cases.
- Specifically in the water utility management community, deformation data can also help monitor and regulate groundwater withdrawals—filling in gaps between spatially limited ground-based sensors. The community sees this scenario as a promising use case, but one with limited operational adoption so far because the cost of InSAR processing is seen as a potential barrier to further adoption. In general, this community desires a better understanding of groundwater resources, potentially enabled by deformation data.
- Specifically, in the property geohazard risk analysis community, users are interested in using subsidence data to improve the accuracy of risk models. Without subsidence data, models can underestimate flood risk and building damage risk. These challenges are of increasing importance to the community, and this increasing importance may drive adoption of subsidence data in the future. But for now, users in this community rarely use subsidence data in their decision-making.

Soil moisture and SWE data

- Soil moisture and SWE data are seen as critical, in addition to precipitation, river flow, groundwater, and other data, in predicting droughts and managing resources during droughts for water utilities and power utilities, as well as real estate and insurance. These data could inform decisions at a daily (for the utilities) and annual (for all communities researched) scale. Better coverage of SWE at low altitudes and spatial resolution is seen as improving utilities' current forecasting and management decision-making.
- Specifically, in the property geohazard risk analysis and power utility management communities, higher spatial resolution soil moisture data could help inform more accurate modeling of the risk of floods and fires.
- Soil moisture also supports water and wastewater pipeline leak detection in the water utility management community. Here, the data can reduce nonrevenue water–related losses and prevent damage to utility assets. Higher temporal resolution L-band quad-pol data are seen as critical for unlocking the potential of this use case, which is growing but not yet broadly adopted.
- Soil moisture data may play a role in supporting irrigation decision-making in agriculture, but many agrochemical companies are skeptical it can play more than a supporting role to on-the-ground data without daily repeat rate.

Vegetation and biomass data

- The agricultural field analysis community values SAR data to inform crop classification, yield models, fertilizer management, and other applications. Some applications are SAR driven, but in many cases, SAR acts as a complement to other EO data or helps fill in the gaps in optical data, which can be a significant challenge.
- SAR data are a significant driver of deforestation monitoring tools; these data are already at least a complementary if not primary data source for this use case today. Users view L-band data from NASA as promising to enhance this use case, but C-band works relatively well, so if there are challenges accessing NASA data for operational use cases, adoption could be slow.
- SAR-derived woody biomass data (density and height) may enable conservation finance use cases (e.g., forest carbon trading), estimation of fire destructiveness for insurance risk models, and identification of risks to power lines. These use cases are in the early stages of or have not yet been adopted by commercial users.
- In current mineral exploration use cases, SAR is useful as a supplement to optical products, including in vegetation-masking tools.

Land cover data

The property geohazard risk analysis community wants more frequent updates to the U.S. land cover map (currently updated every 5 years) and other land cover data to act as an input to flood and fire models, and these data may also be useful to power utilities and others modeling flood and fire risks.

Ice and permafrost data

Ice and permafrost data are not as broadly adopted for decision-making by the commercial users RTI engaged in this study; however, property insurers do have a growing desire to understand permafrost melt impacts on the assets they insure, and in rare cases, offshore energy platforms analyze maritime ice to inform safety decisions (e.g., should the platform by moved at great cost, or is breakup of floes feasible).

Familiarity with and use of SAR data vary significantly across user communities.

SAR communities of practice profiled in this report were **sustainable forestry, agricultural field analysis, O&G infrastructure management, and mineral exploration and extraction**. For these communities:

- EO data experts at intermediary organizations typically drive the use of SAR and other EO data; these organizations are generally well positioned technically to evaluate and adopt future NASA SAR products.
- Continuity, reliability, and ease in accessing data are top priorities—often higher priorities than any specific data attribute or product.
- Desired improvements to the EO data user experience include more seamless access to data products via a simple API, easy cloud-to-cloud transfers of thousands of files, cloud-based snipping tools to reduce file sizes (but removing unneeded data) before exporting, removal/avoidance of seat limits for any organization, and assurance of consistent file-naming conventions (to ensure user programs remain operational).
- Continuity with PoR data collection methods was raised as a critical need to enable time-series analyses in many communities; lack of continuity (e.g., inability to combine SDC, NISAR, and Sentinel-1 data sets easily) could significantly delay, reduce, or prevent SDC data from being valued in some use cases.
- Typically, these organizations prefer to work from Level 0 or SLC data products. They would potentially value higher level products, especially those that would simplify workflows. But lack of standardization for higher level products across SAR data providers makes them wary to build their internal processes around higher level products. Lack of standardization is a problem because users source data from multiple providers to incorporate into their workflows; they need to source files of the same type (e.g., SLCs) to enable easy integration into their workflows. Before adopting higher level products, they want more global standardization for higher level SAR products across both government and commercial providers.
- Typically, SAR and EO expertise is provided as a service to end users through external intermediaries. The agricultural field analysis community is relatively unique in having SAR experts in-house at some of the largest companies in the community (i.e., agrochemical companies).

There is less familiarity with and use of SAR data in the **property geohazard risk analysis, water utility management,** and **power generation and distribution** communities. In these communities of potential for SAR data, note that:

- Although the property geohazard risk analysis community has limited experience with SAR data, they have some experience with SAR and significant experience processing other EO data. EO data intermediaries in this community (typically external to large insurance and real estate companies, although some insurers have internal EO experts) will likely be able to learn how to incorporate SAR data into their models if a clear beneficial use case is identified. They may be able to work from SLCs but would be open to and sometimes prefer to access higher level data products.
- Of the communities profiled, the water and power utilities communities have the least experience with SAR data, and most organizations in these communities have limited familiarity with EO data processing in general. Exceptions to this rule are water resources consultants and startups beginning to offer EO-based services to meet the needs of utilities. Besides these users, end users primarily access high-level EO data products through federal or state government partners. Water resources consultants and startups, as well as government partners, are the primary avenues through which use of SAR data in these communities can increase.

A better user experience accessing EO data and continuity were often on par with, or a higher priority than, specific data attributes across communities.

This analysis reflects the input shared by a representative selection of users engaged through one-on-one interviews and a series of focus groups, during which users discussed their priorities and needs with RTI, NASA scientists, and other users in their community. These takeaways are illustrative, but not exhaustive, of users in each community.

The table below reflects key data attributes and priorities for each user community. User preferences for spatial resolution, temporal resolution, spectral band, and polarization varied not just by community, but also by use case within each community. The values in **bold** in the table do not necessarily work well for all use cases in the community; these **bold** values are instead provided to indicate a value acceptable to most use cases in the community.

Table Legend

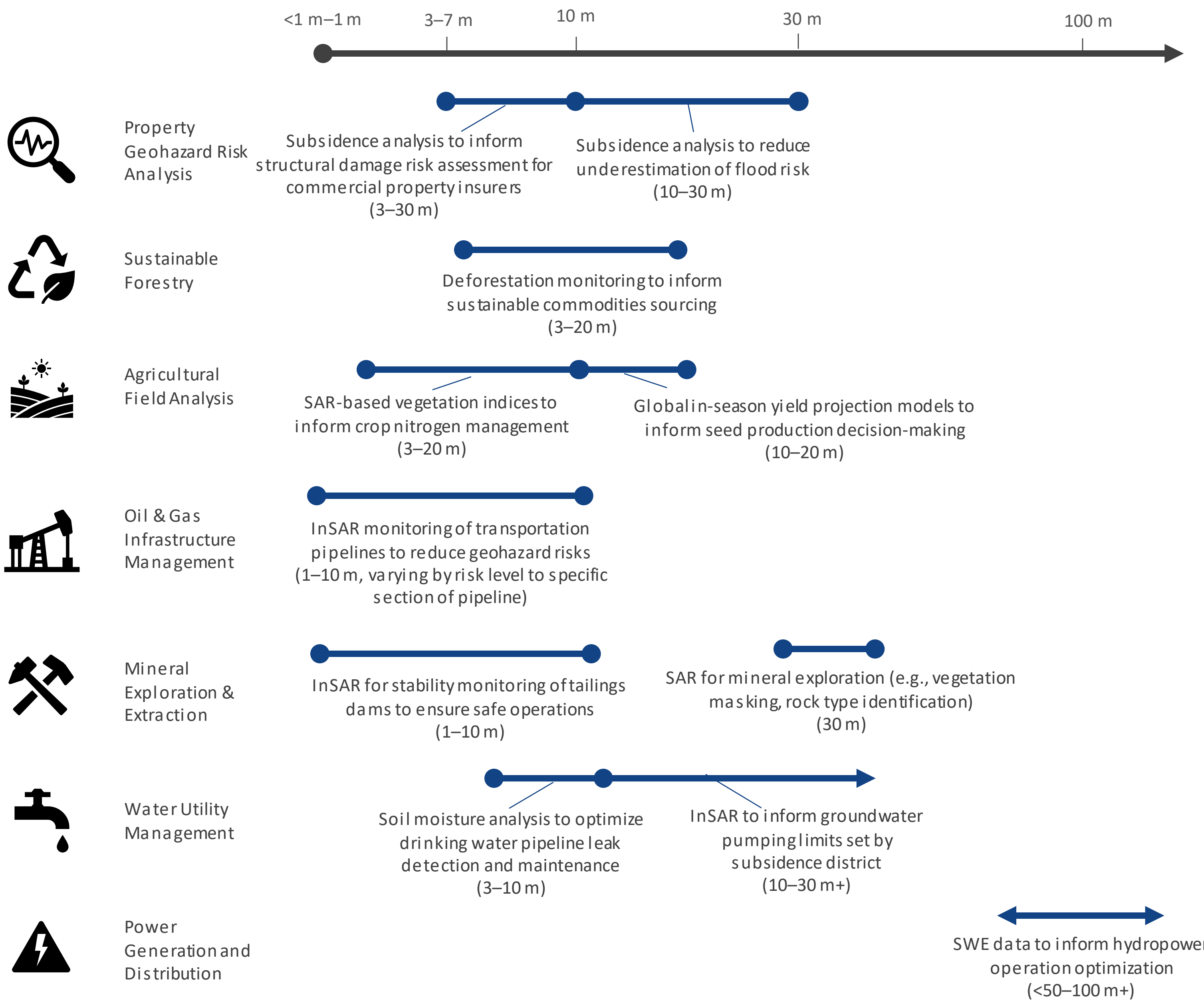
Valued Data Attributes	**Valued in Most Community Use Cases** Ranges are (best-case attributed; preferred)—(worst-case attribute where data still valued)
Data Attribute Priorities	Highest Priority Expressed by Community Engaged in RTI Study
	High Priority Expressed by Community Engaged in RTI Study
	Valued But Not a High Priority Expressed by Community Engaged in RTI Study

User Community	**Valued Data Attributes and Priorities**							
	Spatial res.	Temporal res.	Spectral band	Polarization	Latency	Coverage area	Continuity	Other
Property Geohazard Risk Analysis	**10 m** <3–30 m	**7-day** Daily-monthly	**L-band** but others valued	**Dual-pol** single-quad	**Daily to weekly** Low priority	**Global** especially valued outside U.S.	**Long (15–30) year time series desired** though data useful before this point	Higher temporal res. land cover maps
Sustainable Forestry	**10 m** 10–30 m	**7-day** 2–10 days	**L-band** but C-band similar in value	**Dual-pol** dual-quad	**Daily** 1–3 days	**Global**	**PoR-like** in collection and swath	**Better user experience**; SAR-optical fusion tools or products
Agricultural Field Analysis	**10 m** 3–20 m	**7-day** 2–10 days	**Multiband**	**Dual-pol** dual-quad	**Daily** <24 hr–3 days	**Global**	**PoR-like** in collection and swath	**Better user experience**
Oil & Gas Infrastructure Management	**5–10 m** 3–10 m	**7-day** Hourly-weekly	**Multiband** But L-band unique value	**Single pol** Single-quad	**Daily** 2–3 to 36 hr	**Global**	**Long (5–10+) time series desired** for historical analyses	Dual-look geometries and **better user experience**
Mineral Exploration and Extraction	**10 m** 1–30 m	**7-day** Daily-monthly	**Multi-band** but L-band unique value	**Single/multi** Single-quad	**Daily** for safety critical use cases	**Global** to support exploration workflows	**Long time series helpful** for historical analyses	**Better user experience**, dual-look geometries, higher temporal res. DEMs
Water Utility Management	**Variable** 10–100 m	**Daily-Monthly** Daily-annual	**Multi-band** but L-band unique value	**Quad pol** Dual-quad	**Daily** <24 hr–3 day	**Watershed-Regional**	**Long time series helpful** for historical analyses	Lower cost InSAR processing
Power Generation and Distribution	**Variable** 10–100 m	**Daily-Monthly** Daily-annual	Nonspecific	**Dual pol**	**Daily** <24 hr–3 day	**Regional-National**	**Long time series helpful** for historical analyses	Easier path to understand available NASA products

10-m SAR data are valued for use cases across these communities, but for some, it may be combined with higher resolution data to improve decision-making.

Across communities, users stressed that their data attribute preferences are specific to use cases, and even for a given use case, preferences vary based on the project budget and other constraints. For global coverage use cases (e.g., deforestation monitoring, global in-season yield projection models), users generally employ a fixed number of one or more data sets (e.g., Sentinel-1 SLC files only) to build models that inform decision-making. For site-specific, project-oriented use cases (e.g., InSAR monitoring of transportation pipelines to reduce geohazard risk), service providers may combine multiple data sources of varying spatial resolution and cost to meet project needs; for example, high-resolution data may be sourced in high-risk areas, like near fault lines or river crossings.

Selected Spatial Resolution Preferences

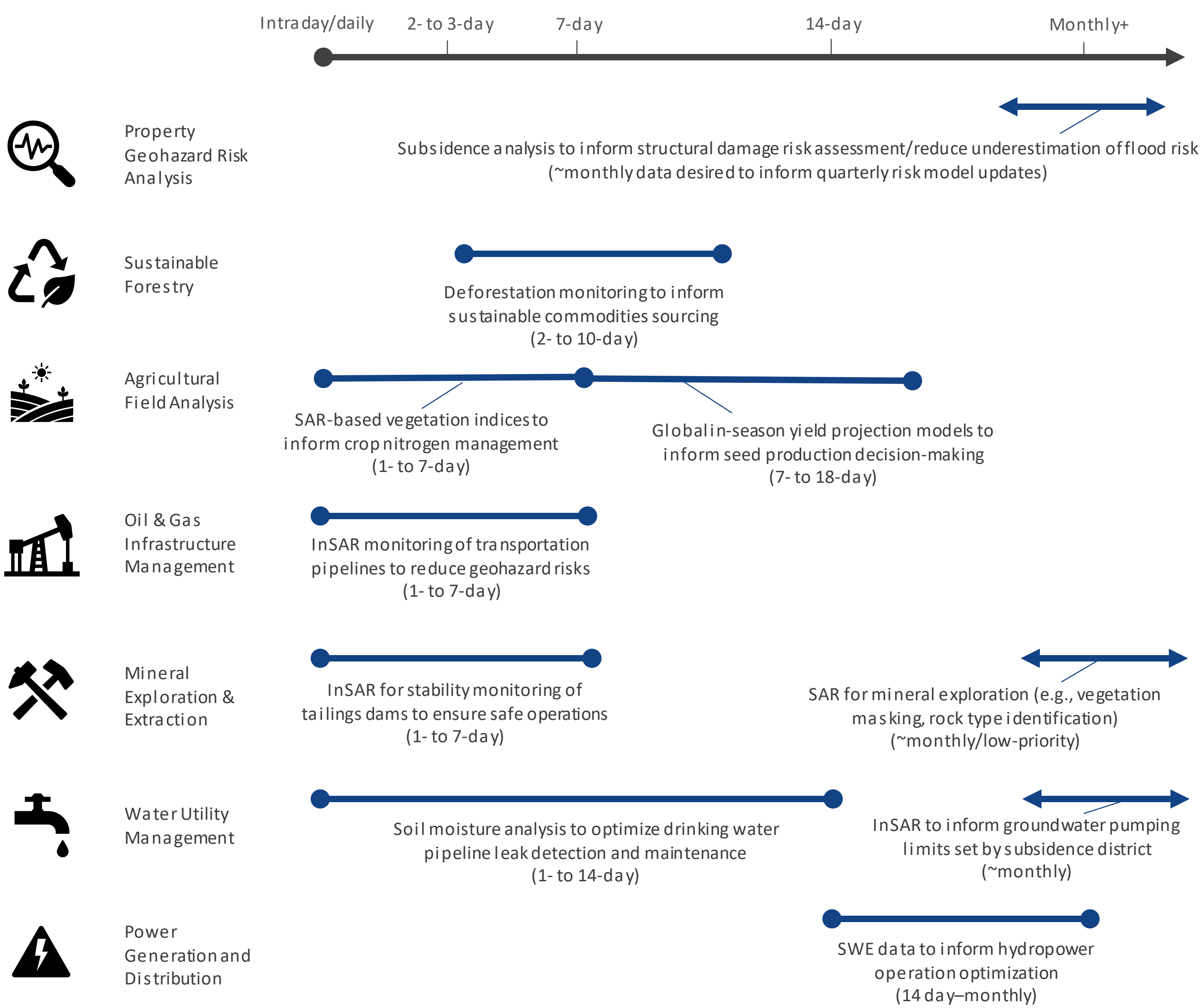


This graphic is not exhaustive of all use cases within these communities or of all use cases discussed in this report. This selection of use cases illustrates the spatial resolution needs across all communities profiled.

Temporal resolution needs range from daily to longer than monthly repeat rates; multiple data sources may be combined to achieve target repeat rates.

For more regular, operational (daily or weekly decision-making), and sometimes safety-critical use cases, temporal resolution (along with latency) is typically a high-priority attribute that defines if a data product is viable for a given use case. Notably, many EO-based service providers combine multiple data inputs (e.g., data from many SAR constellations) to obtain a desired temporal resolution for a given project. Thus, for any data product, failure to meet a specific use case's temporal resolution need may not mean the data are not valuable in that use case; it does mean the data may have less utility in that use case. For long-term risk forecasts (e.g., subsidence analysis to reduce underestimation of flood risk, InSAR to inform groundwater pumping limits set by subsidence district), temporal resolution and latency are less critical.

Selected Temporal Resolution Preferences



This graphic is not exhaustive of all use cases within these communities or of all use cases discussed in this report. This selection of use cases illustrates temporal resolution needs across all communities profiled.

Beyond spatial and temporal resolution, other data attributes are seen as critical to enabling potential SDC use cases.

Spectral bands

- Users across most communities expressed that L-band data from NISAR, and later SDC, would be critical to improving or enabling their use cases. Across communities, L-band is valued for vegetation penetration.
- In some mining use cases, L-band provides unique value given the severe deformations occurring on site; phase unwrapping procedures are simpler with L-band in these use cases because of the longer wavelength. However, users in this community also expect to need high-resolution X- and C-band data to satisfy their monitoring needs.
- O&G pipeline monitoring users see L-band as potentially extending the viability of services in the arctic beyond the "shoulder seasons"—a 4-month summer period during which snow cover does not negatively affect SAR-based pipeline monitoring. NISAR is seen as an opportunity to better understand the utility of L-band in this region. Like in mining, users in this community expect to also need high-resolution X- and C-band data to satisfy their monitoring needs.
- Agricultural use cases benefit from a variety of SAR and other spectral bands, so users in this community expressed a strong desire for multiband SAR data. For these users, L-band is particularly useful (compared with X- and C-band) for crop classification (because it can better distinguish between crop classes) and for soil analysis (including soil moisture analysis) because of its ability to penetrate denser crop canopies. Leading agrochemical firms expressed that if they had to choose one spectral band, they would likely choose L-band for crop classification and soil moisture (over X- and C-band), and they would choose X-band for detecting in-field ponding and crop lodging. But users stressed significant benefit would be derived from multiband SAR availability. Beyond C-, X-, and L-band, multiple users in this community expressed interest in P-band to provide deeper insight into plant and soil properties; one noted P-band does not appear to be of interest to commercial SAR vendors.
- In the sustainable forestry community, users expressed that L-band should provide less noisy data for forest change detection compared with C-band, but that it is too early to say if this offers any valuable benefit or advantage over C-band in that use case; they say NISAR will make this clear. They also said L-band would be valued for its ability to enable more accurate carbon stock modeling and canopy classification (via forest structure/moisture content from the SAR data) to improve forest characterization; this is seen desirable for improving both deforestation monitoring and supporting reforestation use cases.

Polarizations

- Users with use cases focused on soil moisture, SWE, biomass, and vegetation-related observables see dual-pol observations as critical to their use cases.
- Users who can work from single-pol data do see some benefit from the availability of dual-pol data.
- Many engaged users (e.g., agrochemical companies, SAR-based leak detection service providers, deforestation monitoring service providers, mineral exploration service leads) expressed that quad-pol data would significantly benefit their use cases. For agricultural and forestry-related use cases, quad-pol data were seen as nice to have but not more important than meeting the spatial or temporal resolution needs of the use cases. For mineral exploration and soil moisture–based leak detection use cases, quad-pol data are seen as critical in enabling the use case.

Look geometries

Lack of dual-look geometries for high temporal resolution and free SAR data in North America was identified as limiting the expansion of commercial SAR monitoring services for stability monitoring services to O&G companies, mining companies, and water utilities.

NASA is seen as a "lifeline," enabler of innovation, and accelerator for use of EO data by intermediaries processing EO data for end users today.

VASPs gain power from "the giant behind them"; without NASA satellites and data infrastructure, big companies would not engage with them.

Use of SAR data requires specialized skills that are often aimed at niche applications and enabled by small organizations or business units that act as intermediaries between the data and end users. NASA's investments and communication about future plans are critical to the success of these firms or business units and their ability to bring the data to private-sector users to enable economic, environmental, and societal benefits.

"The operational and satellite-based observations for remote sensing are still a young infrastructure. If NASA works with service providers to improve accessibility, stability, and communication on plans and changes, adoption will accelerate."

– SAR-Focused VASP

"What NASA should consider is leading on the technology front—enabling quad-pol and other specs—and letting private sector uncover and develop innovative ways to exploit the data commercially."

– SAR-Focused VASP

In some industries, EO data adoption will accelerate when an innovative leader enters the market such that others will need to follow to compete.

Adoption of new enabling technologies to create new products and change markets is associated with first-to-market advantages, but also is often hindered by status quo inertia. Existing market solutions often are entrenched in various risk models and workflows. In some SAR-based applications, if NASA empowers an innovative solution (via one of many engagement mechanisms) that results in an industry leader adopting the solution, the rest of the industry will follow, as will the acceleration of EO data use in that application. Without NASA as part of the momentum behind these efforts, they will take longer to emerge.

"The insurance industry is quite traditional, yet climate issues are quickly arising, and remote sensing data is an obvious tool for which most companies lack understanding and capacity."

– SAR-Focused VASP

"If a reinsurance company starts to use remote sensing data, the rest will have to follow suit."

– Former Reinsurance Map Product Developer

"Government involvement to help use remote sensing (maybe with regulation) for better management of nitrates will have real environmental upside."

– SAR-Focused VASP

Increasing awareness and capabilities associated with using SAR data will drive further commercial use.

Even in user communities that significantly benefit from SAR data today, end users have little familiarity with EO data.

SAR-based service developers face challenges communicating the value of EO-enabled solutions to their customers, who typically have limited to no familiarity with the concept that NASA and other organizations capture EO—much less the potential benefits of EO data to their decision-making.

"Making the hard-core science more approachable for public consumption and use in improving public's quality of life is key to future success of programs."

– Commodity and Risk Management Executive, Ingredient Company

"If I was to ask 1,000 farmers what NASA was doing for them, I'd get 1,000 befuddled looks and head shakes."

– Former EO Technology Lead, Agricultural Platform Co.

"Even just an increase in the level of awareness about the potential of SAR data would be beneficial for the market and the applications."

– Executive, SAR-Based Service Provider

Increasing end-user awareness of the benefits of EO data—in the context of decisions that matter to them—can meaningfully drive increases in the use of EO data.

Across communities—but especially in the agricultural field analysis community—users stressed the need for clear demonstrations of benefits of EO data in the context of a specific, business-critical use case to drive adoption.

"If innovative farmers hear about satellites before we arrive [to sell services], that's really helpful … ESA is doing really well evangelizing satellite data. People know about Copernicus [in the EU]. But radar data is still a high unknown."

– Executive, Sar-Based Service Provider

"You can't use a research paper done on three small farms in Iowa as evidence that [a new field analysis tool] is globally proven and ready for commercial use."

– Technical Lead, SAR-Based Service Provider

Industry partnerships, as well as training events and research collaborations, can help communicate the value of NASA SAR data to end users.

Industry partnerships, training events, and improved collateral can help communicate the value of NASA SAR data to end users.

Industry-focused training opportunities and research collaborations could help potential users better understand EO data in the context of their decision-making, and industry partners can help communicate the benefits of EO data to end users. Live monitoring platforms, beyond only static marketing sheets, can help make the value and benefits of EO data more "real" to end users and serve as collateral for engaging them.

"NASA would be well served to partner, in some capacity, with the bigger ag companies that have touchpoints at the farm gate. To help [NASA] message what they're doing and communicate the value of the data. This would help obfuscate the 'mystery' of NASA … most growers have no idea NASA provides Earth observations and data products."
– Former EO Technology Lead, Agricultural Platform Co.

"It would be great to have a live map of somewhere, like Yellowstone, where we could show clients live-monitoring with SAR data and other data. To make it real for them. The NISAR page shows a picture of a volcano that's not actually NISAR data; when it launches, we need collateral showing real, live data."
– Technical Lead, Mining Industry-Focused VASP

"'Think like an entrepreneur'—show value, explain access, case studies."
– Commodity and Risk Management Executive, Ingredient Company

Existing professional industry networks and research organizations enable understanding needs and communicating data-product value.

Plugging into professional networks can help NASA engage directly with data users, gauge their level of knowledge and interest in data products, and ultimately disseminate data products and communications about data product changes. Recommendations from users in this direction included global, regional, and technical networks and associations.

"Collaboration with geospatial associations and space-business associations are helpful for both sides."
– Technical Lead, Mining Industry-Focused VASP

"BlueTech Research is the premiere and common landing site for the water industry … having them [explain EO use cases] adds some validity, because we and our competitors already trust them, and they know our world."
– Innovation Lead, Water Technology Company

NASA can engage the private sector through R&D to help develop next-generation data products, improve the data user experience, and unlock new use cases.

Private-sector stakeholders can be leveraged to provide consistent feedback on high-level data product development.

NASA could lean on the private-sector communities of practice for SAR to continue to understand how particular user communities use, could use, and value new data products. Building from the RTI user-centered research, NASA should continue to bring in the voice of different customers as data products are developed. Users want to use high-level data products in their workflows, but lack of availability and standardization prevents this.

"We want to process from Level 3 products, but there are no standards … each provider users different pre-processors or cleaning. The Level 1 products from space agencies are the most stable (so easier to use)."

– Executive,
Deforestation Monitoring
Service Provider

"To achieve more modern data formats and easier access to ready-to-use products for ag-specific applications—that requires partnership with industry and NASA … we need to go beyond the 'logo sharing' of past engagement programs to something more meaningful, with specific targets to make real progress."

– Geospatial Engineering Lead,
Large Agrochemical Company

"It's costly for us to correct for elevation of Sentinel-1 data in-house; but we do it. We'd like it if NASA did it."

– Data Scientist,
Large Agrochemical Company

"Working groups on data standards/ documentation are also good; they can help connecting private company needs w/public."

– Data Scientist
Agricultural Platform

R&D collaborations could also help prove out new use cases of interest.

R&D projects executed with a given user community, in conjunction with NASA support and data resources, could help create a basis for the adoption of EO data in new use cases. For example, for O&G pipeline monitoring, it is unclear how NISAR might affect the ability to provide monitoring beyond the shoulder season in Arctic areas. In the property geohazard risk analysis community, the incorporation of subsidence data into flood models is of interest but not yet demonstrated in commercial use.

"Potential for multipol SAR for surface compositional mapping is quite interesting. This potential was always touted by CCRS for Radarsat-2, but this application was never developed or demonstrated."

– Technical Lead,
Mining-Focused EO Service Provider

"We would be interested to partner with NASA to combine our SAR and AIS expertise to develop maritime ice shipping lane applications when the time is right."

– Technical Lead,
SAR-Focused Service Provider

NASA has an opportunity to build on its support for SAR communities of practice to help grow broader use of SAR data in the communities.

The table is informed by interactions with a representative selection of users in each community who were engaged through one-on-one interviews and a series of focus groups, during which users discussed their priorities and needs with RTI, NASA scientists, and other users in their community. The following four communities have greater levels of SAR use than other communities profiled in this report.

Key Takeaways	Potential Pathways Forward for NASA
Sustainable Forestry Community	
• SAR brings significant reliability enhancements over optical data because it enables consistent data availability for deforestation monitoring in cloudy regions, especially in the tropics. • Data processors see free data as essential to commercial use cases given their expansive monitoring needs. • Speckling can be a challenge for SAR image quality; tools or data products to address this problem could be valued.	• Prioritize engagement (e.g., workshops designed to ease transition to incorporation of NASA SAR data into workflows based on Landsat or Sentinel-1) here because there is a natural synergy between NASA and community organizations (from EO service providers to FMCG companies buying carbon offset credits) in wanting to tell the story of the power of EO data in enabling sustainable business decision-making. • Address community concerns about switching costs (e.g., normalizing harmonizing data, creating new training data, creating new models) to go from Sentinel-1 to NISAR or SDC and the EO data user experience to ensure NASA SAR data are valued.
Agricultural Field Analysis Community	
• SAR is a current key driver of commercial yield estimate models at large agribusinesses, and it is also used in various other use cases beyond the scale of field management decisions. • Currently, agrochemical companies and value-added service providers (VASPs) spend significant time and internal resources correcting (radiometrically and for elevation) Sentinel-1 SLC files to enable their global use cases. They want to work together to achieve more modern data formats and access methods that make commercial use easier. • In most use cases beyond field management and in some field management use cases, 10-m data products delivered every 2 to 3 to 7 days will be valued. But many decisions at field scale require higher spatial and temporal resolution data.	• Work with private-sector firms to develop next-generation data products that improve use cases for agrichemical firms, farmers, and agricultural insurers. Commercial crop modelers want to have a more technical working relationship with NASA to codevelop data products ideal for commercial use cases. • Recognize that agrochemical companies and VASPs are convinced of the value of EO data in this community, but farmers are relatively unaware and unconvinced of the value of EO data. Work with private-sector organizations to increase awareness of and champion the commercial applications of EO data with end users. Using trusted, existing relationships and communication channels can help NASA go further and faster in this community than they go could alone. • Recognize that farmers are squeezed financially from all directions and that some potential EO data use cases with societal value (e.g., reducing nutrient pollution) do not provide a driver for farmers to learn about and adopt EO-based solutions. Private-sector firms can help NASA delineate science-focused and commercially relevant use cases. Use cases driving real financial value should be prioritized.
O&G Infrastructure Management Community	
• The industry has already adopted InSAR for monitoring of pipelines at specific areas of high geohazard risk (e.g., near fault lines). • Risk tools that provide certainty in decision-making are desired by pipeline owners across all pipelines, not just in high-risk areas. However, limited spatial and temporal resolution, vegetation penetration, and look geometries over the United States have made it challenging for monitoring service providers to deliver "certainty" to O&G clients with Sentinel-1. NISAR or SDC may help expand adoption across long pipeline assets.	• Recognize that organizations in this community may be hesitant to engage directly with NASA. They may be wary of new technology solutions that impose higher costs (e.g., by way of new regulatory requirements they must adopt at their own expense) on their business. • When engaging them, consider the risk they perceive and work to mitigate it. • Consider there may be significant opportunities for cross-agency collaboration between NASA; the Department of Transportation, through the Pipeline and Hazardous Materials Safety Administration; and the Department of Energy efforts to address pipeline monitoring needs; these partners have already built trusted relationships with key end users in this community.
Mineral Exploration and Extraction Community	
• Using InSAR in pit mine and tailings dam stability management has a clear business case, which has led to significant increased adoption of InSAR in the mining industry in recent years. • NASA L-band data will be highly valued because the longer wavelength is key to phase unwrapping procedures for use cases with large deformations; however, users expect to use various SAR bands/resolutions to meet client needs.	• Leading EO-based service providers value NASA, but they are generally well positioned to adopt new NASA SAR products without significant support from NASA. • Recognize that EO service providers want reliable data access and a better use experience (to ensure no delay in informing safety-critical decisions), and they would value communication of longer time horizons for SAR missions to help assure their clients that monitoring solutions are here to stay. • Increase the use of SAR data with research and development collaborations or peer-reviewed research specific to mineral exploration use cases.

RTI Innovation Advisors

For communities of potential, NASA might look for opportunities to provide technical support to improve use of EO data (including, but beyond, SAR).

This table reflects key takeaways and potential pathways forward for the remaining three user communities, which have lower levels of SAR experience and understanding. The table is informed by interactions with a representative selection of users in each community that were engaged through one-on-one interviews and a series of focus groups. Users discussed their priorities and needs with RTI, NASA scientists, and other users in their community.

Key Takeaways	Potential Pathways Forward for NASA
Geohazard Risk Analysis Community	
• Currently, flood risks are the primary concern to risk modelers in the real estate and insurance industries; SDC can improve flood risk models by accounting for subsidence. • Subsidence impact from aquifer drawdown and permafrost melt are of growing concern because of the associated potential for building damage, and commercial property insurers look for ways to capture this risk in their models. • To inform models that forecast future hazards, long time-series, free, expansive data are valued over high spatial and temporal resolution data. • Improved temporal resolution on land cover national maps would improve fire forecasting.	• Recognize that organizations in this community have significantly invested in existing risk models, and they can be risk averse in adopting new models and data sources. Further, those processing EO data for this community may be hesitant to discuss technical modeling approaches with peers. Recognize these factors and develop programs that support that culture. Design programs that organizations are comfortable participating in without expectations for shared visibility into internal processes in return. • Ensure data products enable long time-series analysis (e.g., combining Sentinel-1 and NISAR data easily) to enable the long time-series analysis desired by this community. • Enable developers of flood models in this community, both private and public, by providing technical support to help incorporate subsidence data into their models. • If possible, partner with the U.S. Geological Survey to increase the refresh rate of the land cover national maps, targeting a 1-year update frequency.
Water Utility Management Community	
• InSAR is valued to complement ground-based, spatially limited subsidence measurements in monitoring groundwater depletion, but the cost of InSAR software limits use in this community. • InSAR can improve dam and levee management, and surface water extent may help manage dam flood risk. However, temporal resolution needs are intraday in order to replace existing safety-critical, ground-based sensors. • Higher temporal resolution quad-pol L-band data are desired for polarimetry-based water and wastewater leak detection. • Enhanced SWE data products would improve drought prediction; granular soil moisture data could help manage droughts.	• Work to unlock the barrier to scaling use of InSAR for monitoring groundwater withdrawals. Existing users said the cost of InSAR software is a barrier. NASA should further engage these users to determine if (1) high-level data products from NASA can obviate their need for InSAR processing internally and (2) solutions that reduce the cost barriers associated with InSAR processing for these users can be found. **Across both communities:** • Decision-makers value SWE data products. Consider engaging these communities together in the future if NASA gains additional insight into the communities' SWE data product needs. • Using SDC data can benefit these communities, but SDC data play a more complementary role to other EO data in potential use cases than a driver role in many cases. NASA should consider this fact and not lead with SAR data products when engaging this community. • Because they do not have significant EO expertise in-house, utilities rely on external partners, including federal agencies (e.g., NOAA regional river flow forecasting centers) and private-sector consultants to enable their use of EO data products. Ensure that future NASA engagements with this community recognizes this fact. Direct engagement with utilities can help NASA understand their data needs, but utilities will need NASA, other government organizations, or private-sector partners to incorporate EO data into high-level data products before use.
Power Utility Management Community	
• Enhanced accuracy and coverage area for SWE products would improve hydrogeneration asset management. • Soil moisture, surface water extent, and SAR-based activity monitoring could help manage power distribution risks related to drought and fire and right-of-way management.	

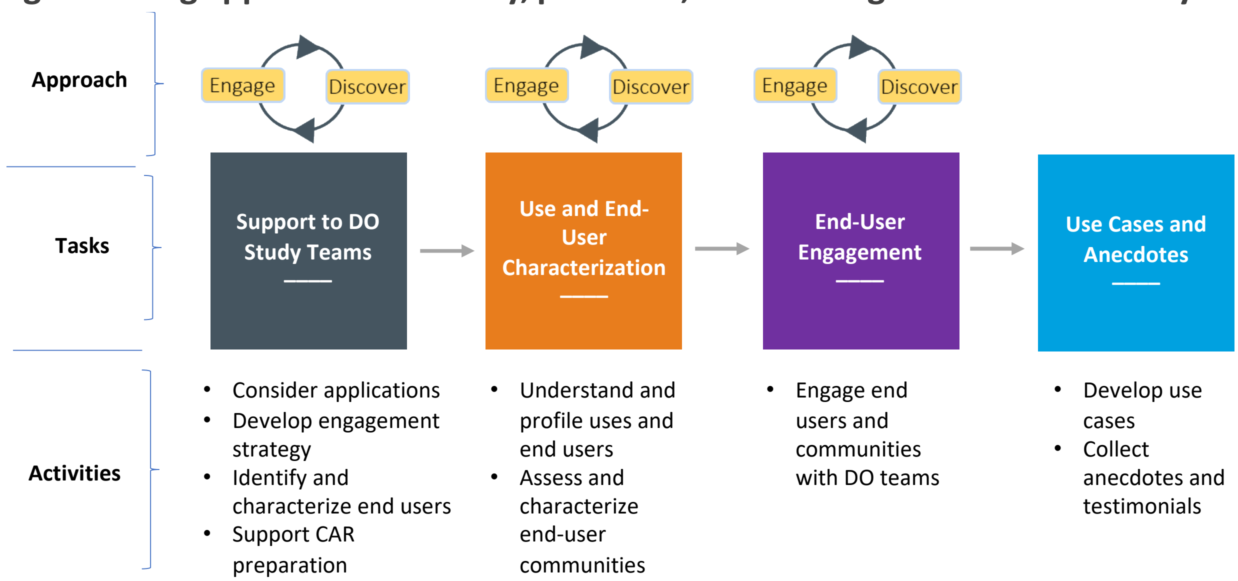
Note that in the context of this report, the property geohazard risk analysis community includes real estate investors, insurers, marketplaces (i.e., an online platform where buyers, sellers, and other real estate stakeholders can interact and learn or share about specific properties), and others working to **forecast the risks geohazards pose** to property. The study did not focus on organizations that use SAR data to **respond to geohazard events**, although some companies (i.e., insurance companies) from the property geohazard risk analysis community may also be involved in those activities.

Sections

Methodology

The goal of this study was to provide support to the SDC R&A team in identifying and characterizing potential end users for the future SDC mission, with a focus on private-sector and nontraditional users. The potential users identified through this study provided insights into their needs, uses, and motivation for using data and data products that could be created from the future SDC mission. The insights from these users may help increase the overall value and benefits from the future SDC mission. The more data attributes and products that align with broader user needs, the greater the opportunity for their adoption of these products.

A design thinking approach to identify, prioritize, and investigate user community needs



Because the goal of the study was to *uncover* new potential users within nontraditional areas, our methodology was based on design thinking principles. This approach enabled the SDC R&A and RTI team to tackle the task of finding potential users of future mission data and understanding their needs and priorities.

To kick off the project, we designed and conducted two virtual workshops that included the SDC, MC, and ACCP applications teams to surface the broader teams' thoughts on private-sector industries and applications for these future missions. Through the workshops, we identified areas where multiple DOs may benefit from joint discussions with end users and created a common base of knowledge to launch our efforts.

RTI then employed our "industry observer" approach, identifying and interviewing people who represented industry perspectives and who could identify potential use cases within their industries. We also conducted secondary research to look for application areas, users, and intermediaries related to SAR-based tools and analyses. The SDC and RTI team met biweekly to discuss and prioritize these potential use cases and companies.

We designed a virtual focus group format to uncover insights into these users' needs, applications, and drivers. Each focus group ranged in size from 8 to 15 people from user companies, NASA, and RTI. These focus groups included a combination of written input and conversations and provided SDC R&A team members with the opportunity to dig deeper into technical and other details from these potential users' inputs. The output of these conversations and previous interviews is summarized in this report.

RTI Innovation Advisors

RTI and SDC collaborated to select areas of interest, resulting in selecting seven diverse user communities.

Initial brainstorming with the SDC team, feedback gathered from NASA-Indian Space Research Organization ISRO Synthetic Aperture Radar (NISAR) activities,[1] and the SDC science application traceability matrix (SATM) were used to guide initial outreach to various user communities. After 50 interviews with existing EO data users and NASA experts, RTI prioritized a long list of potential user communities across several factors (see next page). The goal was to select communities for profiling that are (1) most likely to value synthetic aperture radar (SAR) data products NASA might provide, which are expected to align with areas SDC may have the highest utility to meet Decadal Survey goals as mapped out in the SDC SATM, and (2) driven by private-sector actors to build beyond research communities already being engaged through NISAR activities. As shown in the figure below, the communities selected and researched span SDC's multiple thematic areas.

User Communities	Property Geohazard Risk Analysis	Sustainable Forestry	Agricultural Field Analysis	Oil & Gas Infrastructure Management	Mineral Exploration and Extraction	Water Utility Management	Power Generation and Distribution
	Real estate investors, insurers, marketplaces, and their service providers working to quantify the risks geohazards pose to property	Deforestation monitoring and alert service providers enabling sustainable decision-making in fast-moving consumer goods companies and other organizations	Commercial growers, agribusinesses, crop consultants, insurers, and other agricultural service providers interested in understanding agricultural fields	Oil and gas asset owners and their service providers, who work to reduce environmental and financial risks associated with their infrastructure	Mine asset owners and their service providers, who work to safely and profitability identify and extract minerals from the ground	Water utilities and their service providers, working to efficiently predict and manage local water supply risks and maintain associated infrastructure	Power utilities and their service providers, working to understand and mitigate risks associated with power generation and distribution
SDC Thematic Areas							
Solid Earth	●			●	●	●	○
Hydrology	○		○			●	●
Ecosystems	○	●	●	○	○	○	○
Cryosphere	○			○		○	○

Closed circles (●) indicate thematic areas for which user communities were most interesting in using SDC observables per feedback gathered during this study. Open circles (○) indicate additional thematic areas for which SDC observables were of interest.

1. As per the NISAR Mission Science Users' Handbook, NISAR is a multidisciplinary radar mission to make integrated measurements to understand the causes and consequences of land surface changes activities. Its activities are relevant to this study because many NISAR data users may also be future users of SDC SAR data products.

RTI Innovation Advisors

During outreach, RTI weighed multiple factors and worked with SDC to prioritize communities for further engagement and profiling in this report.

The factors summarized in the upper table (below) were used to consider interview feedback in the context of user community prioritization within this study. Notably, RTI focused on engaging with commercial actor-driven communities in this study and those not deeply engaged during NISAR activities, so lack of prioritization by RTI does not indicate a poor fit of any community with SDC attributes. Also, it is important to note that at the time of this study, specific data attributes of SDC are unknown; attributes mentioned in the table below, however, were seen as useful in considering potential user communities.

Factors used to characterize SDC user communities during the down-selection process for this report

	Commercial actor driven	*Value of SAR*	*Value of L-band*	*Value of expansive and free data set*	*Value at ~10-m spatial resolution*	*Value at 3- to 7-day repeat rate*
High	Users are primarily commercial organizations	High value compared with on-the-ground and other satellite data	L-band is critical to some or all identified use cases	Key use cases likely not well served by tasking commercial satellites	~10 m clearly acceptable or preferred in key use cases	~3- to 7-day repeat rate clearly acceptable or preferred in key use cases
Medium	Mix of commercial and government decision-makers	Some value compared with on-the-ground and other satellite data	L-band is complementary to other data	Some use cases benefit or ancillary benefits to key use cases	Some use cases benefit or ancillary benefits to key use cases	Some use cases benefit or ancillary benefits to key use cases
Low	Users are primarily government organizations	Limited value compared with on-the-ground and other satellite data	L value not differentiated from or worse than other SAR frequencies	Use cases suitable to tasking commercial satellites or nonsatellite data	Limited/niche or no benefit of 10-m data in most use cases	Limited/niche or no benefit of 3- to 7-day repeat rate data in most use cases

RTI characterization of SDC user communities during the down-selection process for this report

User community	*Commercial driven*	*Value of SAR*	*Value of L-band*	*Value expansive and free data Set*	*Value at ~10-m spatial res.*	*Value at 3- to 7-day repeat rate*
Selected for profiling in this report						
Property geohazard risk analysis	**Medium-high:** mainly commercial, actors	**Medium:** fire, subsidence, and flood risks can be addressed	**Medium-low:** benefit if properties are under vegetation cover	**High:** need for long time-series analysis across distributed holdings	**High:** with focus on portfolio-level risk analysis	**Medium:** temporal resolution not critical (except for floods)
Deforestation monitoring	**Medium-high:** some nonprofits enabling private sector	**High:** due to cloud cover challenges with optical data	**Medium-high:** due to vegetation penetration through canopy	**High:** because supply chains are globally distributed	**High:** spatial resolution not critical due to large harvest extents	**High:** multiple firms confirmed as optical ~50 days in cloudy regions
Agricultural field analysis	**High:** agrochemical, farmer, finance, and others	**Medium:** due to regional cloud cover challenges	**Medium:** situationally valued along with other bands and optical	**High:** due to expansive/global areas where data are needed	**Medium-high:** precludes most R&D and some field-management decisions	**Medium:** precludes most R&D and some field-management decisions
Mineral exploration and extraction	**High:** decisions driven by private sector	**Medium-high:** critical in stability monitoring, nice to -have elsewhere	**High:** Critical to unwrapping due to rate of deformation	**Medium-low:** low for stability monitoring, some benefit in other use cases	**Medium:** some decisions may benefit from higher resolution	**Medium-low:** some decisions require daily repeat
Oil and gas infrastructure management	**High:** decisions driven by private sector	**Medium:** some decisions may be made with ground/other satellite data	**Medium-high:** O&G assets under vegetation or seasonally snow cover	**High:** widely distributed, expansive assets	**Medium:** some use of Sentinel-1 today, may need higher resolution for broad adoption	**Medium;** some use of Sentinel-1 today, may need higher resolution for broad adoption
Water utility management	**Medium-low:** private sector supports often government-owned assets	**Medium-high:** drought/flood management and leak detection	**Med-low:** L-band may be preferred in some use cases	**Medium-high:** some monitoring needs over expansive watersheds	**Medium:** acceptable in many use cases, but higher resolution has benefits	**Medium:** acceptable for many use cases, safety-critical needs faster data
Power utility management	**Medium-low:** private sector supports often government-owned assets	**Med-high:** snow, surface water, and soil moisture inform operations	**Low:** L-band critical use cases not surfaced in outreach	**Medium-high:** monitoring needs over expansive areas	**Medium-high:** acceptable in many use cases, but higher resolution has benefits	**Medium-low:** data beneficial as one of many model inputs
Commercial forestry management	**High:** decisions driven by private sector	**Medium-low:** limited cloud cover challenges as required repeat rate low	**Medium-low:** niche applications due to vegetation penetration through canopy	**Medium-low:** Lidar costs high, but seen as needed for single-tree resolution	**Medium-low:** niche value in fire or pest response only	**Medium:** annual or longer updates acceptable for core commercial uses
Construction planning and liability analysis	**Medium:** commercial led; often government clients	**Medium-low:** one of many data points, but unique deformation insights	**Medium-low:** benefit if properties are under vegetation cover	**Medium-high:** long time series strengthens all use cases	**Medium-low:** 10 m has some value but higher ideal	**Medium-low:** value when the only option, may leave gaps in liability analysis
Landslide Monitoring & Risk Analysis	**Medium-low:** private sector supports often gov't owned assets	**Medium-high:** enables landslide monitoring and triage of on-the-ground sensor placement	**Medium:** benefits related to vegetation penetration/coherence	**Medium-high:** historical time-series has large benefit	**Medium:** acceptable in many use cases; but higher-res has benefits	**Medium-low:** limits use cases not appropriate for many safety-critical applications
Maritime ice hazard analysis	**Unclear:** Limited feedback	**Medium-low:** capable of identifying/analyzing ice, but low commercial use	**Medium:** complements C-band and enables thickness analysis	**Medium-low:** most common decisions focus on specific assets	**Unclear:** Limited feedback	**Unclear:** Limited feedback

For communities not profiled in this report, RTI captured initial insights from limited engagement.

The findings below are based on limited engagement with organizations in communities not profiled in the full report. These findings may be useful in informing future engagement with these communities, but they are based on interactions with only two to three organizations per community; as such, the findings are of lower confidence than the findings for the communities profiled in this report.

Commercial forestry management community

- One VASP with clients in the forestry sector expressed that commercial forestry companies may be interested in using SAR data if the data can obviate their need to use Lidar, which is currently flown over expansive forest assets to provide high-resolution data. They said that *"[t]ons of our customers want biomass analysis for forestry applications, and SAR can provide real estimates of stem sizes, trunk sizes, etc. You need lots of algorithms and assumptions to get there from optical data … today our forestry customers are so desperate [for better data]; they want to walk the whole forest with Lidar. But it's too expensive over expansive areas. So, our forestry customers are really interested in yield potential estimates with SAR to solve this."*
- A commercial forestry company's geographic information system (GIS) analyst stated they would find limited utility in SAR data in the context of replacing their Lidar mapping because of the perception that SAR data would not provide sufficient spatial resolution. They explained they use Lidar for single-tree forest inventories in which a point represents a tree in the forest, and that from these data they can estimate the number of 2x4s from an area before it is harvested and milled. They said this Lidar provides 16 points per square meter and is typically collected by the forestry company every 10 years at high cost (e.g., a multimillion-dollar project for a 650,000-hectare forest). Critically, they said because of the slow rate of tree growth, there is limited value in faster repeat rates; they said even over a 10-year period there would only be ~5% biomass volume change.
- The same GIS analyst noted that an exception to this slow temporal resolution need in their decision-making is in cases related to natural disturbance (e.g., pests, forest fires) tracking; they use Sentinel-2 and Landsat data for this today and stated 10-m SAR data could be useful as well. They noted that, as a forestry company, they do not need to take actions to address fires. However, they do need to understand the impact of the event afterward because it informs, in some cases, harvesting (e.g., timber can be salvaged post-fire, but the "timer" starts after the fire). They noted sometimes government may ask them to specifically go to and harvest burned areas, but that in these cases government partners typically provide the needed data.
- The same GIS analyst said they recently explored buying high-resolution satellite data to test if it could be used as a supplement to or instead of Lidar mapping; they said they typically must order imagery from fixed-wing contractors about once a year for 30-cm data at significant cost. They said their goal is to understand what tree species and volume exist, as well as terrain factors (including moisture). They said they think 50-cm satellite data may be needed for this type of assessment, and they are unsure if it can meet their needs. They said there is a challenge in forestry because the resolution needed for most on-the-ground operations (e.g., 5- to 10-m data, as operations are directed using consumer-level GPS with similar resolution) is insufficient for regulatory reporting requirements, so even if 5- to 10-m data were acceptable for decision-making, they would still have to obtain higher-resolution data.

Construction planning and liability analysis community

- One insurer focused on construction liability noted that *"for insurers, adopting SAR data is aimed at avoiding liability; it's a loss control concept. They do not want to pay the homeowners for their basement cracking if the construct project did not cause the crack."*
- One project manager at a construction company explained:
  - Every tunnel job is set up with ground monitoring at the surface and in the tunnel, and all jobs have geotechnical investigations prior to the job (but who pays varies). All bid and build work is done by the owner or designer or construction management group as part of a bid package (not bound to the contract) and includes historical data. The more work the owners, designers, or construction managers do, the more successful. Most owners are ultimately government funded. For industry, on some bids, the geotechnical analysis is an investment in creating a smart bid. Having a geotechnical baseline and monitor during and after a project can have value to document prior to build and as-built conditions to act as a baseline in addressing later complaints.
  - Beyond operational needs, most tunnel projects have regulations and insurance considerations that dictate monitoring; some of these exist as these projects are typically related to government assets. All projects require ground monitoring and movement, often vibration monitoring because of explosives use, and subground monitoring (via a subcontractor), which are typically analyzed daily to provide "fair warning" if movement.
  - He theorized asset owners are less likely to use InSAR directly but could benefit from it through existing service providers. He said a lot of owners do not invest in enough analysis at the design stage because of cost, but that investing could lead to better long-term economics. He said that with poor analysis upfront, *"[the construction company] gets paid to do more"* and the water inflow realities are much worse during and after.
- One InSAR expert noted they have clients in the civil engineering sector, especially related to urban tunneling projects and structural health monitoring.

Landslide monitoring and analysis community

- Interviews with internal NASA stakeholders indicated there was likely a limited market for landslide monitoring for **commercial organizations** and that the primary involvement of the private sector in landslide monitoring was through the provision of services for government clients.
- Multiple InSAR experts noted they have supported landslide monitoring use cases for government clients, but that such use cases were limited. One expert noted some companies do specialize in this type of work. Along with monitoring landslides, that expert stated InSAR can also be used to triage the placement of on-the-ground sensor assets (which are needed to provide appropriate temporal resolution in event of a landslide).
- One InSAR expert noted most of the interest in landslide monitoring is related to “fast landslides” and that slow landslides are primarily interesting in geological studies.
- A microinsurer expressed interest in SAR data for landslides, but they noted they do not have expertise processing SAR. They explained that floods are very relevant and barely covered [with insurance products] in Central America. They said that currently flood insurance in the region is typically tied to rainfall. They said this could be improved, because this approach does not account for river flooding, landslides, or other flooding sources. They also noted that secondary to better flood and landslide data, other hazards including volcanic eruption could be interesting to insure against too.
- One SAR expert stated that in forested or vegetated areas, L-band is particularly key for landslide monitoring They said that they are aware that China uses a lot of L-band data today for monitoring forested areas where landslides are frequent; they said they understand NASA is building their own L-band satellite to serve their future data needs.

Maritime ice hazard analysis community

Note that maritime ice hazard analysis in the context of oil offshore platforms is covered in the oil and gas infrastructure monitoring user community profile in this report.

Feedback from three SAR service providers indicated that currently ice analysis was low priority for the maritime navigation community and, as a result, SAR-based ice hazard use cases are not yet mature. Two leading microinsurer SAR service providers predicted the market will exist in the future. This feedback led RTI to not profile the community in this report. Specifically:

- One SAR service provider stated they have done commercial sea ice monitoring work with SAR data, but it is rare. They said they could not provide details of the work because it is confidential. In considering potential data needs in maritime ice hazard analysis, the service provider stated: *“For ice monitoring, revisit and latency are very important, but those operational parameters can be addressed with more [satellites] or ground [hardware] if the detection probability is sufficient. My gut feeling is that L-band and X-band would complement C-band as the primary source and help assess ice thickness. L-band may not be as good at detection of young ice, but perhaps would give less noise from water surface when mapping older ice floes. I'm not sure of the use of quad-pol L-band for ice, it may be less useful at discriminating ice type than quad-pol C-band and perhaps co-pol L-band might give most of the benefit for improved S/N.”*
- A different SAR service provider stated that there is *“not much commercial SAR [use] for [maritime] shipping yet, but that use case is not a matter of if but when. We would be interested in leveraging our SAR and AIS capabilities to predict pathway of ice in shipping lanes.”*
- A different SAR service provider told RTI that they expected it would be challenging to convene a focus group related to SAR for maritime sea ice navigation as *“maritime sea ice clients don’t exist yet.”* They said that Spire and other firms are beginning to collaborate around SAR data for maritime use cases though, wherein SAR is used to track ships after their transponders go off. The service provider suggested that there could be opportunities to build from this use of SAR data in the maritime industry at some point in the future, but that for now ice is low on the priority list of shipping companies.

Railroad infrastructure management community

- One organization in this community was engaged and indicated interest in evaluating InSAR data internally to determine if it could provide utility in railroad track maintenance use cases. They said they were not aware of anyone in the North American rail market using satellite data, and they thought it seemed promising for making railroads more proactive and less responsive/reactive. They said 12-day repeat InSAR over Mexico, the United States, and (mostly southern) Canada would be of broad interest to their company and industry. They said along with track maintenance InSAR could also inform where new track is laid (though they noted this use case is less common).
- ESA’s RailSAT program (https://business.esa.int/projects/railsat) conducted a feasibility study into the use of SAR for rail management. At the time of this writing, the “Current Status” of this project indicates that for *“success of the envisaged service it is a prerequisite that specific rail technical issues can be detected from satellite Earth observation data at an early stage of their occurrence. As part of a Proof of Concept, no technical correlation between satellite data and relevant in-situ events could not be established. Due to this lack of technical feasibility, a viable business case could not be elaborated, and the Feasibility Study was closed.”*

RTI would like to recognize the individuals at the following organizations who supported this study.

User Community	Organizations Engaged
Property Geohazard Risk Analysis	AXA XL, APG Asset Management, CGG, ClimateCheck, FM Global, Hazard Hub, MiCRO, Stantec
Sustainable Forestry	Mars, Hershey, Trimble, Descartes Labs, Esri, Satelligence, World Resources Institute, Arbol
Agricultural Field Analysis	6 Grain, Bayer Crop Science, Climate Corporation, ConserWater Technologies, Corteva, Cropix, Oak Ridge National Lab, Planet Watchers, REFARMO, Sarmap, Freshwater Trust
Oil and Gas Infrastructure Management	CGG, Esri, Geofinancial Analytics, iPIPE Partnership, Occidental Petroleum, SkyGeo, TRE ALTAMIRA, Ursa Space, Xylem
Mineral Extraction	CGG, Descartes Labs, Occidental Petroleum, SkyGeo, TRE ALTAMIRA, Ursa Space, Utilis, Xylem
Water Utility Management	Arizona Dept. of Water Resources, INTERA, New Hampshire Dept. of Environmental Services–Water Division, Rezatec, Utilis, Xylem
Power Utility Management	Duke Energy, Great River Hydro, Idaho Power, Rezatec, Tennessee Valley Authority
Other	Canfor, Kiewit Corp., Railinc, and many organizations above that work across communities