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Commercial Smallsat Data Acquisition Program On-ramp #2 Airbus U.S. Synthetic Aperture Radar (SAR) Evaluation Report

Batuhan Osmanoglu, Jaime Nickeson and Alfreda Hall

October 2023

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NASA

Commercial Smallsat Data Acquisition Program

On-Ramp #2

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Executive Summary

In 2017, NASA's Earth Science Division (ESD) launched the Private-Sector Small Constellation Satellite Data Product Pilot, now referred to as the Commercial Smallsat Data Acquisition (CSDA) program. The objective of CSDA is to identify, evaluate, and acquire commercial remote sensing data that support NASA's Earth science research and application activities. The Pilot successfully concluded in early 2020, when CSDA transitioned into a sustained program with on-ramping opportunities for new vendors as the industry emerges with new candidates and capabilities.

In October 2019, a Request for Information (RFI) seeking capability statements from parties interested in providing data from spaceborne platforms was released for the CSDA on-ramp #2 evaluations. To be responsive to the RFI, the commercial satellite constellations had to consist of three or more operating spacecraft actively collecting data in a non-geostationary orbit with full latitudinal coverage and be U.S. companies.

Two vendors responded to the RFI and were evaluated by a committee composed of NASA ESD leadership, program managers, and scientists. Both vendors satisfied the RFI requirements and were asked to respond to a Request for Proposal (RFP). After review of the proposals, NASA entered into a Blanket Purchase Agreement (BPA) with Airbus Defense and Space GEO, Inc. (Airbus) U.S. in September 2021 and with BlackSky Geospatial Solutions, Inc. (BlackSky) in November 2021.

In this report, CSDA provides an evaluation of the usefulness of data provided by the Airbus U.S. Synthetic Aperture Radar (SAR) satellite constellation, consisting of TerraSAR-X (launched in 2007), TanDEM-X (launched in 2010), and PAZ (launched in 2018), for advancing NASA's Earth system science research and applications. The evaluation of the BlackSky commercial data will be provided in a separate report.

To conduct the Airbus evaluation, NASA's ESD augmented 13 existing research projects that could potentially benefit from, and had the expertise to evaluate, the commercial data being considered for longer-term purchase. Investigators from NASA's Research and Analysis Program science focus areas and from NASA's Applied Sciences Program elements participated in the evaluation. A summary of the research areas evaluated by the Principal Investigator (PI) teams is presented in Figure 3. CSDA also funded a dedicated activity to evaluate the satellite data quality (calibration and geolocation) independently by assessing the accuracy of data from Airbus.

Evaluation activities were carried out by the selected PIs from December 7, 2022, to December 7, 2023. Delivery of datasets requested by the researchers began in January 2023. The vendors were evaluated on the accessibility of data, accuracy and completeness of metadata, and promptness and quality of user support services. Datasets purchased during the evaluation have been archived by NASA and will be made available to current and future government-funded researchers in accordance with the End User License Agreement (EULA). This synthesis report distills and integrates the findings of research reports commissioned by NASA for the Airbus evaluation. This report also includes recommendations that inform the way ahead for the program.

The scientific results from the evaluations demonstrated that the commercial data from Airbus were able to advance NASA research and applications. However, the PIs encountered limitations that diminished the usefulness of the data due to the amount of effort that was required to access, preprocess, and analyze these data. One significant issue encountered was the limited spatial and temporal coverage of the data in the Airbus archive that could be used to conduct time series analyses or assessments over large spatial scales. Overall, however, the utility and the quality of the evaluated data outweighed the difficulties encountered, and NASA has concluded that the Airbus SAR data would complement NASA's existing Earth observation capabilities and Airbus U.S. would qualify to participate in the sustained phase of the program.

Background

In 2017, NASA's Earth Science Division (ESD) launched the Private-Sector Small Constellation Satellite Data Product Pilot. After the completion of the Pilot, a new program was established, referred to hereafter as the Commercial Smallsat Data Acquisition (CSDA) program. CSDA was established to identify, evaluate, and acquire data from commercial sources that support NASA's Earth science research and application goals. ESD recognizes that data from commercial systems have the potential to complement existing NASA data sources to advance Earth system science and applications development for societal benefit. During the Pilot, the evaluation team assessed data provided by three private sector vendors that currently operate satellite constellations in low Earth orbit—Planet Labs (Planet), Maxar Intelligence (formally DigitalGlobe), and Spire Global (Spire). The vendors were evaluated on the accessibility of data, accuracy and completeness of metadata, promptness and quality of user support services, suitability of the End User License Agreement (EULA) for standard scientific collaboration, and usefulness of the data and imagery for advancing Earth system science research and applications. Additionally, two dedicated activities were performed to evaluate satellite calibration and geolocation quality of the vendor data.

Results from the Pilot evaluations demonstrated the ability of commercial data and imagery to advance NASA scientific research and applications. However, a significant issue encountered was the highly restrictive EULAs that inhibited standard scientific collaboration. NASA worked with the vendors to maintain access to data and resolve issues encountered. The results of this evaluation were published in the CSDA Program Pilot Evaluation Report, which was released in April 2020 (https://cdn.earthdata.nasa.gov/conduit/upload/14180/CSDAPEvaluationReport_Apr20.pdf).

The Pilot successfully ended in April 2020 and transitioned into a sustained program with on-ramping opportunities for new vendors as the industry emerges with new candidates and capabilities. By June 2021, the CSDA program's license agreements were expanded to broaden the applicability for scientific applications across the U.S. Government. These license uplifts will make the data more readily available across the government and improve both the value of these data and the opportunities for interagency collaboration.

The second vendor on-ramp (on-ramp #2) was initiated in October 2019 with a Request for Information (RFI) seeking capability statements from parties interested in providing data from spaceborne platforms for evaluation. To be responsive to the RFI, the commercial satellite constellations had to consist of three or more operating spacecraft actively collecting data in a non-geostationary orbit with full latitudinal coverage and be U.S. companies. Two vendors satisfied the RFI requirements and were asked to respond to a Request for Proposal (RFP). After review of the submitted proposals, NASA entered into a Blanket Purchase Agreement (BPA) with Airbus Defense and Space GEO, Inc. (Airbus) U.S. in September 2021 and BlackSky Geospatial Solutions, Inc. (BlackSky) in November 2021. The datasets available from the on-ramp #2 vendors are listed in Table 1.

Table 1

On-Ramp #2 Vendors and Sensor Data Available for Evaluation

Vendor	Sensor Type	Temporal Coverage	Spatial Coverage	Satellites	Bands	Resolution
Airbus	SAR	2007/11 – 2022/12	Global	3	X-band	0.24-40 m
BlackSky	Optical	2018 – Present	53.5 N to -53.5 S	16	R, G, B, Pan	0.8-1.5 m

Note. Information on constellation numbers was current as of the start of the evaluation.

In this report, CSDA evaluates the usefulness of imagery and data provided by Airbus U.S. commercial Synthetic Aperture Radar (SAR) satellite constellations for advancing Earth system science research and applications. The evaluation of the BlackSky commercial data will be provided in a separate report. Current information about the CSDA vendors, user licenses, and available data can be found at https://www.earthdata.nasa.gov/esds/csda.

Evaluation Process and Criteria

Evaluation Process

NASA ESD selected and augmented funding for 13 projects (Appendix A) to perform the evaluation. Researchers covered five of the six Earth Science focus areas, including Weather and Atmospheric Dynamics, Climate Variability and Change, Water and Energy Cycle, Carbon Cycle and Ecosystems, and Earth Surface and Interior. The projects covered Research and Analysis (R&A) interdisciplinary science focus areas and Applied Sciences Program elements. The 13 project teams formed the Airbus commercial data evaluation team.

NASA ESD also funded an additional research team specializing in SAR calibration and geolocation to independently assess the radiometric calibration and geolocation accuracy of vendor-provided imagery. The evaluation Principal Investigators (PIs) were required to submit interim, midterm, and final reports and to attend monthly discussions to ensure they had sufficient information and data access to complete their evaluation. Figure 1 presents the breakdown of the researchers by research area. Appendix A provides a listing of the research projects performed during the Pilot.

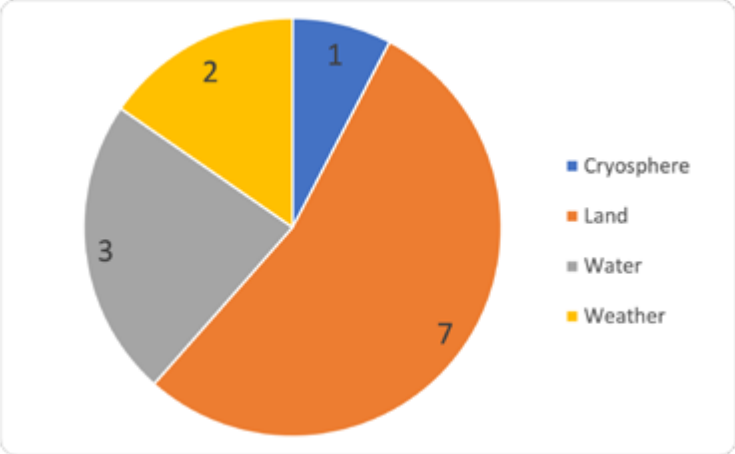


Figure 1. *Researchers by broad science disciplines*

Evaluation Criteria

A. Access, metadata, and support

i. Accessibility of vendor supplied data
The ease and efficiency with which data can be searched, discovered, and downloaded from vendor systems.

ii. Accuracy and completeness of metadata
The accuracy and completeness of metadata that accompanies the imagery and data provided by the vendor.

iii. Quality of support services
The availability, responsiveness, and technical expertise required to answer PI inquiries.

B. Usefulness of the data for advancing Earth system science Research and Applications
The ability of vendor-supplied data to support Earth system science Research and Applications.

C. Quality of vendor supplied data
The quality of data attributes, such as radiometric calibration, geolocation accuracy, and platform intercalibration.

Program Activities

The evaluation was facilitated by conducting periodic reviews and surveys, PI all-hands monthly technical interchange meetings, and community engagement. The evaluation timeline is depicted in Figure 2.

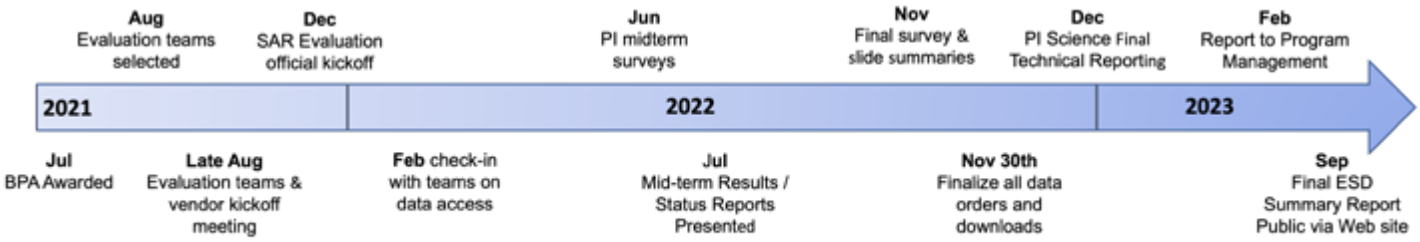


Figure 2. *Timeline of Airbus evaluation activities since awarding the purchase agreement*

Periodic Reviews and Surveys

All PIs were required to participate in periodic reviews and report on the usefulness of the data and current research progress. The PIs were asked to submit progress reports in February and July, followed by a final report in December 2022. A hybrid midterm meeting was held in July 2022 that allowed PIs to share their preliminary results. In addition to the reports, PIs were asked to submit a final report and quad chart as well as complete a survey outlining their final research findings. All reports and surveys were synthesized in the creation of this final summary report.

PI All-hands and Vendor Meetings

There were three of these meetings—a kick off meeting, a midpoint meeting for the PIs evaluating Airbus imagery, and a final debrief. These cross-disciplinary meetings served as check-ins, where the PIs presented and shared their preliminary findings, issues, and concerns while assessing the commercial datasets. For some of the PIs, it was the first time working with Airbus data, thus these meetings proved to be important touchpoints to ensure all PIs had a similar level of understanding of the commercial capabilities and were provided with the proper support for their analyses.

Monthly Technical Interchange Meetings

Monthly video conference calls were set up to facilitate technical interchange among the PIs to provide updates and to resolve issues related to data access, quality, completeness, or processing. The PIs were asked to identify issues and share information they believed to be relevant to other PIs. The conference calls were an effective means of ensuring timely identification of and response to issues, such as challenges the team experienced with bulk data download, radiometric calibration, and black banding

at the edge of scenes due to receive-window variations during imaging. These meetings also allowed the CSDA staff an opportunity to gather and relay issues from the PI projects to the vendors directly to accelerate problem-solving.

Community Engagement

The CSDA program convened oral and poster sessions at the 2022 American Geophysical Union (AGU) Fall Meeting to invite papers on science research and applications that have used the data from commercial vendors. Additionally, the sessions were intended as an opportunity for understanding the challenges associated with the usage and management of commercial data.

As the capabilities of commercial vendors grow, it is important to continuously monitor the development of new commercial technology, acquire relevant data to complement existing and future missions, and evaluate the data over time. CSDA continues to provide status updates, answer questions about data access, and provide information about future procurement opportunities for other constellation owners at various professional conferences (e.g., American Meteorological Society Annual Meeting, European Geophysical Union, etc.) and workshops throughout the year. These community engagements serve as an open forum for dialogue between experts across the science data research stratum and help showcase NASA's progress and commitment to building stronger bonds with the commercial sector.

Key Findings

The key findings from the evaluation are organized into four general scientific areas: cryosphere, land, water, and weather. The evaluation was focused on assessing the utility of Airbus data for advancing NASA's R&A science focus areas and Applied Sciences Program elements. The evaluation mainly focused on the data accessible via the archive. New tasking of data accounted for 2% of the total by number of images evaluated. A summary representing the research areas evaluated by PIs is presented in Figure 3. The key findings address the objectives of the CSDA program evaluation and are described in the sections below.

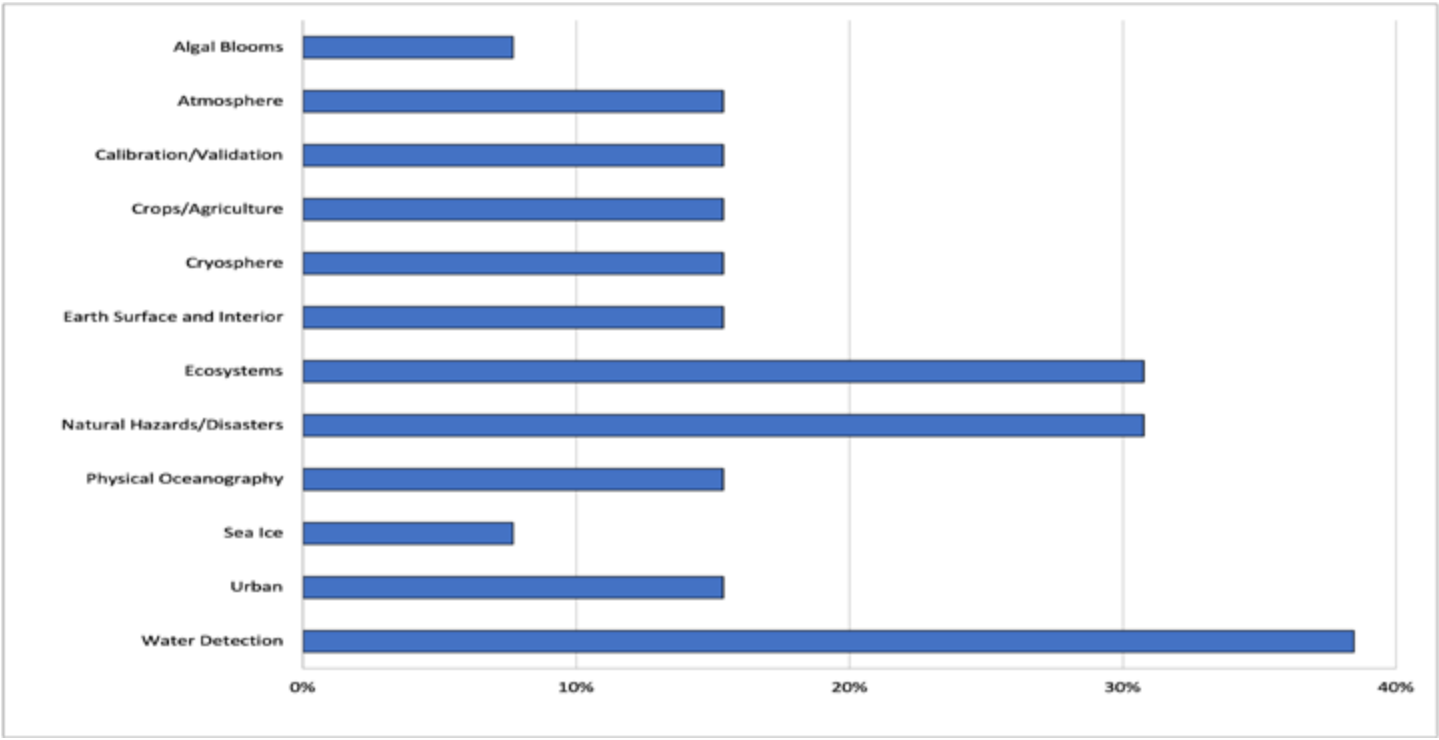


Figure 3. *Evaluation research areas were varied, and some evaluations covered more than one research area.*

The Airbus datasets that were evaluated were acquired through the U.S. Government End User License Agreement (EULA). Per the criteria outlined in section 2.2, the evaluation findings in these areas for the Airbus datasets are presented below.

Data Access, Metadata, and Support

Data Access

Because of the tasking nature of the Airbus systems, the evaluation PIs discovered that even though they had access to the archive for all three Airbus SAR sensors, TerraSAR-X (launched in 2007), TanDEM-X (launched in 2010), and PAZ (launched in 2018), the spatiotemporal coverage of the overall dataset was very limited for conducting long term scientific analyses. Additionally, due to restrictions by research

institutions, about 40% of the PIs faced challenges downloading the data using one of the Airbus-provided download tools.

Airbus provided data access to the PI teams as part of their evaluations. At the beginning of the evaluation process, the PI orders were submitted using an Airbus-generated CSV file. In order to create the CSV file order with the unique Airbus IDs, the PIs had to download the Airbus KMZ archives from https://terrasar-x-archive.terrasar.com/ or visit the site to extract the CSV file. Unfortunately, because the extracted CSV file did not include the required unique scene IDs, an additional intermediate step was needed to generate the unique IDs through a NASA-developed online notebook linking the acquisition times to scene IDs. Another issue was the lack of support for initially extracting nominal scenes from the longer swaths within the portal. Several of the PIs were confused during this stage and had to go through several iterations to get their data. The data ordering process was greatly improved when Airbus rolled out a new version of their portal (https://radarportal.sarapi.intelligence-airbusds.com) soon after the initial orders were submitted. However, the shortened scene length functionality was not available until five months into the evaluation. The new portal was a better fit for NASA's use cases, and it eventually also supported extraction of nominal or shorter scenes from longer swaths. Several PIs recommended improvements, such as the addition of Coregistered Single-look Slant-range Complex (CoSSC) data to avoid ordering by email, a baseline tool to allow users to search data based on repeat track baselines, and use of more intuitive file names in the delivery instead of an order ID.

Documentation and Metadata

Airbus provided documentation on metadata, sensor calibration, and instrument characteristics that aided in the evaluator's ability to validate findings. Most of the PIs found the metadata that were provided with the products to be sufficient. A few of the teams recommended the inclusion of baseline information relative to a notional reference track. Such information would allow the scientists to select the baselines that fit the criteria for their scientific application before they download the data. Similarly, about 25% of the teams recommended that Airbus include the backscatter correction equations directly in the metadata files so that all the information needed for corrections is contained within the product, without the necessity to read through the product documentation.

User Support

Any support provided by Airbus was very good and responsive, earning praises by all the evaluation team members that interacted with the Airbus team.

Data Utility for NASA Science

The utility of Airbus data differs among the Earth science focus areas. In general terms, the usefulness of the data is high for episodic or short-term local studies, but the application of Airbus data for long-term global studies is limited by lack of densely sampled historical data available in the archive. To simplify the reporting of results from the evaluations performed, the following groupings are used: Cryosphere, Land, Water, and Weather.

Cryosphere: Glaciers

The study team found that the temporal sampling of the data was far too sparse to provide any kind of meaningful time series. The team had obtained better results with the openly available, coarser spatial resolution SAR data for measuring glacier surface flow velocities and tracking seasonal variations, due to their consistent temporal sampling.

It is important to note that TerraSAR-X has a long record, having been launched in 2007, but the team reported that with only a few clustered samples for some years, there is no way to resolve seasonal variation.

Where the time series data are available, the team was able to obtain higher resolution flow rates, with better definition over the same area compared to openly available SAR imagery. The data were also found to be well-calibrated and well-geocoded for the purpose of glacier surface velocity determination.

Land: Ecosystems and Solid Earth

For Ecosystems and Solid Earth related research, about 85% of the teams found the Airbus data useful to further their science objectives. Ecosystems teams found the data to be applicable for mapping water height changes in wetlands and for estimating wetland vertical structure using tomographic approaches. The higher resolution of the Airbus data allowed for identification of additional flooded vegetation as well as identification of roads between individual agricultural fields, compared to coarser resolution datasets. The Solid Earth teams indicated that Airbus data provide valuable insights into volcanic processes and hazards. The higher resolution spotlight mode imagery was found to be superior for identifying surface changes on volcanic edifices.

The teams found the data to be artifact free, geometrically well-referenced, and met the stated radiometric performance metrics. Similarly, the noise equivalent sigma naught values and ambiguities were satisfactory for scientific applications.

The impact of vegetation on coherence is dependent on factors such as vegetation density and height. The evaluation teams that were working on agricultural fields, mangroves, wetlands, and forestry applications found the coherence to be lacking with the TerraSAR-X 11-day repeat period. Teams working on areas with less vegetation, such as those working on volcanoes, found that the 11-day repeat period was adequate for coherent observations. It must be noted that with the PAZ mission, Airbus is now able to reduce the interferometric revisit period to 5.5 days, though data were not available over the sites analyzed.

On the other hand, as steep terrain is common on volcanic sites, the teams working at such sites concluded that the shallow incidence angles resulted in significant layover. Furthermore, they found that atmospheric artifacts were more pronounced due to the shorter X-band wavelength.

Water: Surface Water Reservoirs, Sea Ice, and Algae

About 65% of the teams that were working on science disciplines related to water found the Airbus data useful for their research. The calibration and characterization of the Airbus systems were found to be exceptional. The teams also found that strong precipitation events were impacting the ability of their

retrieval algorithms to detect water due to the shorter wavelength of X-band. The team demonstrated that the data were successful at detecting the presence of floating algae and sea ice in the imagery. The tracking of sea ice benefited from the shorter revisit enabled by using all three Airbus satellites as well as the more frequent passes over the Arctic. In terms of sea ice motion tracking, even though the data support correlations at close to native resolution, the resulting motion vectors are noisy, indicating rapid changes in motion that cannot be substantiated through further analysis.

Weather: Severe Weather Impacts

All the PIs working on severe weather impacts indicated that the data are relevant and useful to complement the openly available datasets. They found that the higher resolution of X-band imagery provides a significant and tangible benefit by providing improved flood warnings and disaster planning, greater protection of farmland and food security, and prevention of human suffering. This is mainly due to improved detection of smaller features, from narrow water channels to individual buildings impacted by a tornado.

Data Quality

The quality of vendor imagery has been evaluated by researchers with expertise in SAR analysis to assess the radiometric and geometric quality of imagery suitable for scientific research.

Radiometric Calibration

The radiometric stability of time series and trend analyses from Airbus satellites in support of Earth science research and applications were analyzed. The calibration values were characterized for imagery acquired over the corner reflector array in Rosamond, California, maintained by NASA's Jet Propulsion Laboratory (JPL). All Airbus satellites performed well within their specifications. After radiometric calibration provided with the product metadata and the documentation, all satellites were in close agreement within ±1 dB.

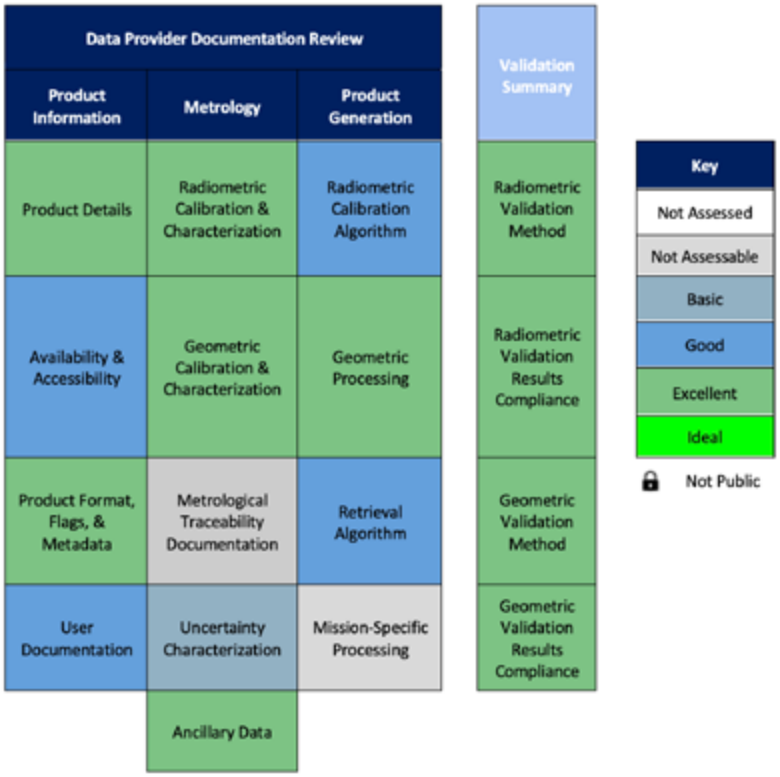
Geometric Calibration

Researchers analyzed the positional accuracy of Airbus imagery against the well-known position of the corner reflectors at the Rosamond corner reflector array. The geolocation accuracy and apparent spatial resolution of the Airbus imagery were found to be sufficient to support scientific analysis at the reported product resolution. Typically, geolocation accuracy for SAR data is tied to the knowledge accuracy of the satellite position in orbit. Images over the Rosamond site had a geolocation accuracy of about 2 m in range and about 0.5 m in azimuth.

For more details on the radiometric and geometric quality assessment, please refer to the Airbus U.S. Synthetic Aperture Radar Quality Assessment Summary report. A summary of the results is presented in Figure 4.

Figure 4

Summary Cal/Val Maturity Matrix from the Airbus U.S. Synthetic Aperture Radar Quality Assessment Summary Report



Recommendations

The NASA-funded PIs were able to evaluate data from Airbus SAR platforms for existing research activities. The characteristics of the data that led to the successful outcomes from the research performed included the data being of high spatial resolution, long temporal coverage (where available), and well-calibrated.

Recommendation: Airbus data were demonstrated to have a sufficient utility for NASA research and application activities spanning multiple thematic areas. Time series studies and studies requiring large area coverage were difficult to conduct due to the tasking nature of the Airbus constellation and the acquisitions in the current archive. It is therefore recommended that the vendor continue to improve data coverage through routine background observations over areas of scientific interest. The overall utility of the data was determined to be sufficient, based on their very high spatial resolution, availability of various imaging modes, and mature calibration. As a result, NASA has concluded that the Airbus SAR data would indeed complement NASA's existing Earth Observation capabilities and Airbus U.S. would qualify to participate in the sustained phase of the program.

Conclusions

Over the course of a year, 13 PIs representing five of NASA's six R&A science focus areas as well as Applied Sciences Program elements evaluated data from Airbus SAR satellites. A significant majority of these evaluations demonstrated the usefulness of these commercial data for advancing scientific research and applications. However, the evaluators encountered limitations that either diminished the usefulness (e.g., limited archive) and/or increased the amount of work needed to access, preprocess, and analyze data (e.g., download services, documentation, metadata, etc.). Overall, the utility of the evaluated data outweighed the difficulties encountered, and it was determined that Airbus U.S. would be a complement to NASA's existing Earth Observation capabilities, thus successfully completing the evaluation phase of the program.

Appendix A. Listing of Evaluation Research Projects

Research Using Airbus Data

- ABoVE Wetlands for Waterfowl X-Band Augmentation (PI: Nancy French, Michigan Tech)
- Assess the suitability of the commercial data to augment NASA project in coastal environments (PI: Marc Simard, NASA JPL/Caltech)
- Augmentation Request A.37 Project: Integrating SAR Data for Improved Resilience and Response to Weather-Related Disasters (PI: Franz Meyer, University of Alaska Fairbanks)
- Evaluation of Airbus X-band SAR data in remote sensing of marine debris (PI: Chuanmin Hu, University of South Florida)
- Improving Reservoir Monitoring and Inundation Forecasting with High Resolution TerraSAR-X and TanDEM-X Imagery (PI: Hyongki Lee, University of Houston)
- Multi-frequency, multi-polarization active-passive sea ice thickness and motion monitoring (PI: Mary Ruth Keller, Johns Hopkins University Applied Physics Laboratory)
- On-ramp #2: SAR Data Evaluation as an Augmentation to Cryosphere Lead for the NASA ISRO Synthetic Aperture Radar Mission Science Team (PI: Ian Joughin, University of Washington)
- Pacay Volcano (PI: Christelle Wauthier, Penn State)
- Quantifying volcanic activity from space with multiple sensors: The CEOS volcano demonstrator project (PI: Matt Pritchard, Cornell University)
- The impact of soil moisture variations on InSAR time series analysis—applications and evaluation of the effect on the NISAR mission and potential for mitigation (PI: Rowena Lohman, Cornell University)
- Understanding the global 3D signature of tree biodiversity with Airbus SAR data (PI: Lola Fatoyinbo, NASA's Goddard Space Flight Center)
- Using Airbus X-band SAR data for Severe Weather Impacts to the Land Surface (PI: Jordan Bell, NASA's Marshall Space Flight Center)
- Vertical structure with InSAR TSX/TDX data (PI: Marco Lavalle, NASA-JPL/Caltech)

Calibration and Geolocation Assessments

- Airbus U.S. Synthetic Aperture Radar Quality Assessment Summary (PI: Batuhan Osmanoglu, NASA's Goddard Space Flight Center)