Commercial SmallSat Data Acquisition Program Pilot

Evaluation Report

NASA Earth Science Division

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Executive Summary

In 2017, the National Aeronautics and Space Administration (NASA) Earth Science Division (ESD) launched the Private-Sector Small Constellation Satellite Data Product Pilot, now referred to as the Commercial Smallsat Data Acquisition Program (CSDAP) Pilot). The objective of CSDAP is the identification, evaluation, and acquisition of commercial remote sensing imagery and data that support NASA's Earth science research and application activities.

During the pilot, the CSDAP evaluated the usefulness of imagery and data provided by commercial small satellite constellations for advancing Earth system science research and applications. A Request for Information (RFI) seeking capability statements from parties interested in providing data from space-borne platforms was released in December 2017. To be responsive to the RFI, the constellations had to consist of three or more operating satellites actively collecting data in a non-geostationary orbit with full latitudinal coverage and be U.S. companies.

A total of 11 vendors responded to the RFI and were evaluated by a committee composed of NASA ESD leadership, program managers, and scientists. Four vendors that satisfied the RFI requirements were selected and asked to respond to a Request for Proposal. After review of the submitted proposals, NASA entered into Blanket Purchase Agreement (BPA) and End User License Agreement (EULA) negotiations with three companies – Planet Labs (now known as Planet), DigitalGlobe (now known as Maxar Technologies), and Spire Global, Inc. (Spire) – for the provision of high spatial resolution multispectral imagery and Global Navigation Satellite System-derived data. The BPAs were awarded in September 2018.

To conduct the evaluation, NASA's ESD augmented 41 existing research projects that could potentially benefit from and had the expertise to evaluate the commercial imagery and/or data being considered for longer-term purchase. At least one researcher from each of the six Research and Analysis science focus areas, Applied Science program elements, and the Heliophysics Space Weather Program participated in the Pilot. The CSDAP Pilot also included two dedicated activities to evaluate satellite calibration and geolocation independently by assessing the accuracy of multispectral imagery from Planet and Maxar Technologies. A summary representing the research areas evaluated by Principal Investigators (PIs) is presented in Figure 3.

Evaluation activities were carried out by the selected PIs from January 1, 2019 to December 16, 2019. Delivery of datasets requested by the researchers began in January 2019. The vendors were evaluated on the accessibility of data, accuracy and completeness of metadata, promptness and quality of user support services, and suitability of the EULA for standard scientific collaboration. Datasets purchased during the Pilot have been archived by NASA and will be made available to current and future NASA-funded researchers. This synthesis report distills and integrates the findings of research reports commissioned by the Pilot. Results are presented for each vendor separately. The report also includes recommendations that inform the way ahead for the program.

Results from the evaluations demonstrated commercial data and imagery advanced NASA scientific research and applications. However, PIs encountered numerous limitations that either diminished the usefulness and/or increased the amount of work needed to access, preprocess, and analyze data. One significant issue encountered was the highly restrictive End User License Agreements (EULAs) that inhibited standard scientific collaboration. Overall, the utility of the evaluated data outweighed the

difficulties encountered, and NASA will work with vendors to maintain access to data evaluated and resolve issues encountered.

1 Background

In 2017, the National Aeronautics and Space Administration (NASA) Earth Science Division (ESD) launched the Private-Sector Small Constellation Satellite Data Product Pilot, referred to hereafter as the Commercial Smallsat Data Acquisition Program (CSDAP) Pilot. The CSDAP Pilot 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 has the potential to complement existing NASA data sources to advance Earth system science and applications development for societal benefit. During the Pilot, the CSDAP evaluated data provided by three private sector vendors currently operating satellite constellations in low earth orbit. The vendors were evaluated on the accessibility of data, accuracy and completeness of metadata, promptness and quality of user support services, and suitability of the End User License Agreement (EULA) for standard scientific collaboration. Additionally, two dedicated activities were performed to evaluate satellite calibration and geolocation and assess the accuracy of multispectral data from Planet and Maxar Technologies.

A Request for Information (RFI) seeking capability statements from U.S. parties interested in providing data from space-borne platforms was released in December 2017. In addition to requesting data, the RFI required that satellite constellations be composed of three or more satellites operating in a non-geostationary orbit with full latitudinal coverage. These requirements ensured vendors would be able to provide data from functional satellites at the start of Pilot evaluation activities, the observation systems had resiliency by having multiple platforms, and supported NASA's mission to conduct long-term global research.

A total of 11 vendors responded to the RFI and were evaluated by a Program Steering Committee of NASA ESD leadership, relevant program managers, and program scientists. Four vendors were selected and asked to respond to a Request for Proposal (RFP). After review of the submitted proposals, NASA entered into contract and EULA negotiations with three companies – Planet Labs (Planet), Maxar Technologies (DigitalGlobe) and Spire Global (Spire) – for the procurement of high spatial resolution multispectral imagery and Global Navigation Satellite System (GNSS)-derived data products. The Blanket Purchase Agreements (BPAs) for the purchase of data were awarded in September 2018. The data sets available from the vendors are listed in Table 1.

Vendor	Data Available	Coverage Period	Platform Number	Bands	Resolution
Planet	PlanetScope Dove Classic	2016 & 2017 +	100	4 (RGB, NIR)	3-4 m
	PlanetScope Dove-R	12/2018 +	22	4 (RGB, NIR)	3-4 m
	RapidEye	10/2009 +	5	5 (RGB, RE, NIR)	5 m
	SkySat	2016 +	15	5 (RGB, NIR, pan)	0.72 m
Spire	GNSS Radio Occultation (RO), GNSS Reflectometry (R), and Precise Orbital Determination (POD)	1/2018 +	89	NA	NA
DigitalGlobe	WorldView-1	9/2007 +	1	1 (pan)	0.5 m
	WorldView-2	10/2009 +	1	8 (pan, VIS-NIR)	1.85 m (0.46m pan)
	WorldView-3	8/2014 +	1	8 (pan, VIS-NIR)	1.85 m (0.31m pan)
				8 SWIR	3.7 m
				8 CAVIS	30 m
	WorldView-4	11/2016-1/2019	1	4 (pan, RGB, NIR)	1.24 m (0.31 m pan)
	QuickBird	10/2001-1/2015	1	4 (pan, RGB, NIR)	2.62 m (0.65 m pan)
	GeoEye	9/2008 +	1	4 (pan, RGB, NIR)	1.65 m (0.41 m pan)
	IKONOS	9/1999-3/2015	1	4 (pan, RGB, NIR)	3.20 m (0.82 m pan)

Table 1 - Vendors and sensor data available from the Pilot for evaluation (information on constellation numbers was current as of the start of the evaluation).

To evaluate the commercial datasets, ESD program managers identified 41 existing NASA-funded research projects whose principal investigators (PIs) had the expertise to evaluate the data purchased. For the remainder of this document, the terms PIs and researchers are used interchangeably. The Pilot evaluation program took place from January 1, 2019 to December 16, 2019.

2 Objectives

The CSDAP Pilot objectives were to assess:

1. *Accessibility of vendor supplied imagery and data*: The ease and efficiency with which data can be searched, discovered, and downloaded from vendor systems.
2. *Accuracy and completeness of metadata:* The accuracy and completeness of metadata that accompanies the imagery and data provided by the vendor.
3. *Quality of user support services:* The availability, responsiveness, and technical expertise required to answer PI inquiries.
4. *Appropriateness of the End User License Agreement (EULA) for scientific research:* The suitability of the EULA to allow PI the ability to practice science.
5. *Usefulness of data and imagery for advancing Earth system science research and applications:* The ability of vendor-provided imagery and data to support Earth system science research and applications activities.
6. *Quality of vendor supplied imagery and/or data*: The quality of data attributes, such as geolocation accuracy, radiometric calibration, and platform intercalibration.

3 Evaluation Process

NASA ESD selected and augmented funds of 41 researchers to perform the Pilot evaluation. At least one researcher from each of the six Research and Analysis (R&A) interdisciplinary science focus areas, Applied Science program elements, and the Heliophysics Space Weather Program were selected. The 41 projects were separated into two groups based on type of data being evaluated. Spire data evaluation was largely performed orthogonally to the Planet and Maxar Technologies segments, because the latter were focused on satellite imagery. Less than a third of the Pilot PIs evaluated multiple vendors for their projects. NASA ESD also funded two research teams specializing in satellite calibration and geolocation to independently assess the radiometric calibration and geolocation accuracy of vendor-provided multispectral imagery. Pilot PIs were required to submit interim, midterm, and final reports and to attend one in-person meeting, with the option of participating in various program activities to ensure they had sufficient information and data access to complete their evaluation. Figure 1 presents the breakdown of the researchers by vendor. Appendix A provides a listing of the research projects performed during the Pilot.

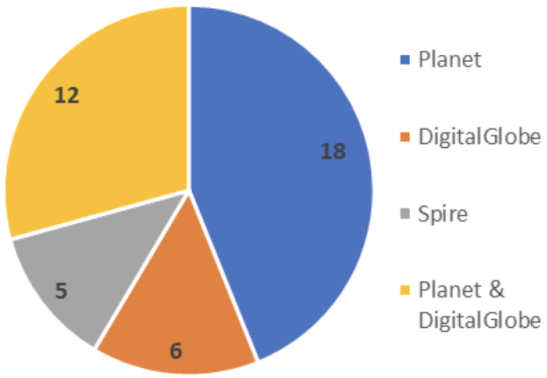

Figure 1 - Researchers by Vendor Summary

4 Program Activities

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

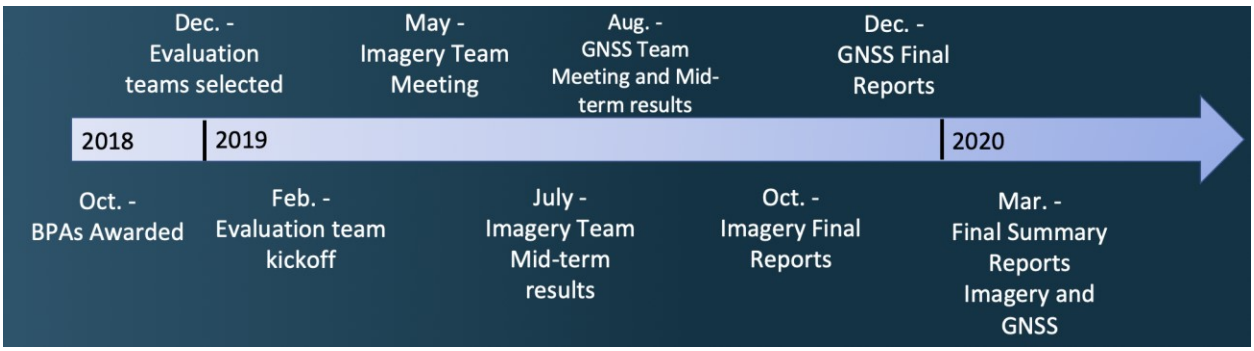

Figure 2 - Timeline of Pilot activities since awarding the purchase agreements (dates in calendar year).

4.1 Periodic Reviews and Surveys

All Pilot 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 March and July, followed by a final report in October (Planet and Maxar Technologies) and December (Spire) 2019. A meeting was held in May 2019 that allowed PIs to share their preliminary results. In addition to the reports, PIs were asked to submit a final report and complete a survey that outlined their final research findings. All reports and surveys were synthesized in the creation of this final summary report.

4.2 PI All-Hands and Vendor Type Meetings

There were three of these meetings – a kick off meeting, a midpoint in-person meeting for the PIs evaluating Planet and Maxar Technologies imagery, and a separate meeting for the Spire PIs. 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 many of the PIs, it was the first time working with commercial data, thus these meetings proved to be vital touch-points to ensure they were provided with the proper support for analyses.

4.3 Weekly Technical Interchange Meetings

Weekly conference calls were set up to facilitate technical interchange among the PIs to resolve any issues related to data access, quality, completeness, and 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 and prompt response to issues, such as challenges with Planet bulk data download, geolocation accuracy, and radiometric calibration. These meetings also allowed the CSDAP staff an opportunity to gather and relay ongoing issues from the PI projects to the vendors directly to accelerate problem-solving.

4.4 Community Engagement

Kevin Murphy, Program Executive for Earth Science Data Systems (ESDS) Program, convened members of the science community on two occasions, during a Town Hall at the American Geophysical Union 2019 Fall Meeting and at a side panel of the 2020 American Meteorological Society Annual Meeting, to provide a status update on the CSDAP, answer questions about data access, and provide information about future procurement opportunities for other constellation owners. This community engagement served as an open forum for dialogue between experts across the science data research stratum and helped showcase NASA's progress in building stronger bonds with the commercial sector.

5 Key Findings

The key findings from the evaluation are organized by commercial data vendor: Maxar Technologies, Planet, and Spire. The evaluation was focused on assessing the utility of data for advancing the six R&A science focus areas, Applied Science program elements, and the Heliophysics Space Weather Program. A summary representing the research areas evaluated by PIs is presented in Figure 3. The key findings address the objectives of the CSDAP Pilot evaluation and are described in the sections below.

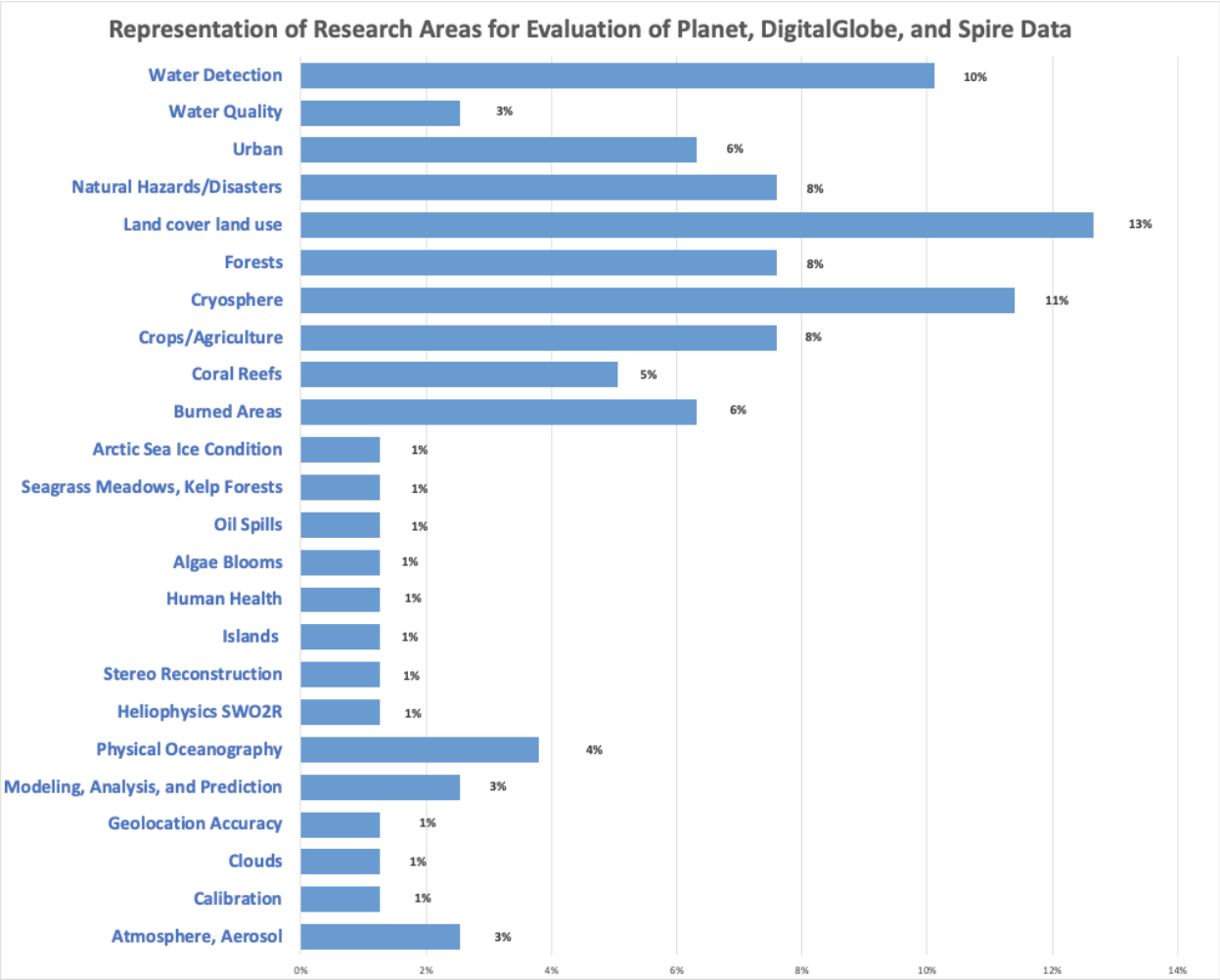

Figure 3 - Evaluation research areas were varied and some evaluations covered more than one research area.

End User License Agreements

Since 1994, NASA ESD communities have primarily conducted activities under ESD's open data and information policy (https://science.nasa.gov/earth-science/earth-science-data/data-information-policy). This policy has enabled researchers to freely collaborate across organizations, share derived products/research results, and support scientific transparency by allowing access to source data used in publications. Additionally, a single open policy has simplified and reduced the costs of data management systems. This open data and information policy had to be revisited for the Pilot because it was cost-prohibitive to purchase large quantities of data from vendors with a fully open license.

Agreements were reached with each vendor that sought to balance scientific factors (collaboration, publication, and reproducibility), data access (a sufficient amount of data was needed to perform global evaluations), and commercial interests. EULAs with all vendors contained similar, but not identical, terms and conditions, including limiting the redistribution of raw data to only small groups of approved users and restrictions on sharing derived products and publication results without vendor approval. While the final EULAs were significantly more restrictive than ESD's current open data and information policy, research groups were able to complete evaluations. However, restrictions in EULAs were

uniformly identified as challenges by PIs and created additional complexity and cost for NASA data management and authorization of approved users.

Maxar Technologies

The Maxar Technologies datasets evaluated during the Pilot program were acquired through the NextView license with the National Geospatial Intelligence Agency (NGA) and NASA's BPA with Maxar Technologies for Worldview-4. The NASA BPA only acquired datasets not available through the NextView license. The agreed upon access method for these datasets was through NASA's existing CAD4NASA project located at Goddard Space Flight Center (GSFC) (https://cad4nasa.gsfc.nasa.gov/). PIs evaluated Worldview-1, Worldview-2, Worldview-3, GeoEye, and QuickBird datasets (via NextView license), and Worldview-4 (via NASA's BPA).

Finding 1: Accessibility

Because NASA had an established partnership and Data Use Agreement with the NGA through a NextView license, CSDAP determined the CAD4NASA system would be the data access method for Maxar Technologies data for the Pilot evaluations. There were no issues with direct data access/download from Maxar Technologies.

Finding 2: Completeness and accuracy of metadata

Maxar Technologies publications provided documentation on metadata, sensor calibration, and instrument characteristics, which aided in PI ability to validate findings. A majority of PIs found that calibration information contained within file level metadata was inconsistent and needed to be updated and manually corrected.

Finding 3: User support services

The CAD4NASA system provided the Maxar Technologies data access for the pilot evaluations. Any support required by Maxar Technologies was very good and responsive.

Finding 4: Appropriateness of End User License Agreement for scientific research

The PIs found the EULA appropriate for evaluation, but license terms inhibited standard scientific collaboration. PIs expressed concerns regarding the terms and conditions of the EULA that prevented them from widely distributing derived products to the scientific community. Further restrictions on the ability to submit source data to journals to recreate experiments were noted. Restrictions related to sharing imagery and data across U.S. federal agencies and partners were also found to be problematic.

Finding 5: Usefulness for science and applications

The utility of Maxar Technologies imagery data differs among the Earth science focus areas. In general terms, the usefulness of Maxar Technologies data is high for localized studies, but the application of data for long-term global studies is limited by availability of data. To simplify the results of the evaluations, the following groupings are used: Atmosphere, Cryosphere, Land, and Water.

Atmosphere: Clouds and Aerosols

Researchers found Clouds, Aerosols, Water Vapor, Ice, and Snow (CAVIS) instrument data to be valuable for characterizing clouds at a spatial resolution of 30 m. That is substantially finer than what is currently available from other sources, like Moderate Resolution Imaging Spectroradiometer (MODIS), with a spatial resolution of 1 km, and Visible Infrared Imaging Radiometer Suite (VIIRS), with a spatial

resolution of 750 m. The products derived from CAVIS complement existing NASA cloud/atmosphere data product lines, but CAVIS's limited data observations diminish suitability for global studies.

The researchers found imagery acquired by the CAVIS instrument aboard the WorldView-3 satellite, which has MODIS-like bands, to be of sufficient quality to provide cloud property retrievals similar to those from MODIS. These included estimates of cloud-top altitude, cloud optical thickness, effective radius, and other derived quantities at a 30 m scale vs. the MODIS 1 km scale, when the CAVIS data, which are not routinely collected, existed. The imagery enabled synergistic research involving aerosols, clouds, and their interactions. The user support, including documentation for CAVIS, was found to be inadequate. However, it is important to note that NASA researchers were among the first external users of CAVIS data. The data could be used in efforts to refine and improve global cloud products and to develop capabilities for continuity of climate data records with existing and future imagers (e.g., MODIS to VIIRS and into the next-gen geostationary era).

Cryosphere: Snow and Ice

Researchers were able to use WorldView data to determine precise surface elevation, surface roughness at the meter scale, and ice stream acceleration at the sub-meter scale.

Data from WorldView-2 (50 cm spatial resolution) were used to determine ice stream acceleration in Greenland, providing heretofore unavailable information on ice sheet dynamics. The data allowed for mapping of fine-scale crevasses. Researchers were able to estimate surface roughness at 2 m spatial resolution for glaciers in the Arctic and on the Greenland ice sheet. Surface roughness is important for understanding ice mass balance and melting. Both of these results were due to the fine spatial resolution and high radiometric quality.

The retrieval of surface topography from WorldView-1, -2, and -3 stereo pairs enabled elevation retrieval at the 50 x 50 cm scale with a vertical accuracy of ±20-30 cm. The high spatial resolution digital elevation models (DEMs) derived from the WorldView data enabled understanding processes in glacial and snow environments and supplemented coarser remote sensing retrievals and energy balance modeling of glaciers in rugged terrain.

The availability of the WorldView near-infrared bands and their high radiometric quality improved the ability to differentiate snow from other bright surfaces. This also enabled mapping debris-covered ice through the expression of underlying ice features in the debris that were expressed at the sub-meter scale.

Land: Agriculture, Forest, Urban

WorldView-2 and -3 multispectral bands are well-suited for accurate feature extraction, classification, and change detection of human-dominated environments. WorldView-2 and -3 pan-sharpened 50 and 30 cm imagery enabled mapping of small-scale agriculture, determination of rural-urban transition, and identified impediments to Giant Tortoise migrations. The 0.5 - 0.3 m WorldView-2 and -3 panchromatic imagery, with segmentation algorithms, resolved field-edge boundaries of very small fields that other satellite data could not. This helps to improve mapping of cropland planted area. WorldView-3 imagery quantified within-field productivity differences with its 30 cm spatial resolution and its Sentinel-2-like bands.

Water: Lakes, Rivers, and Oceans

Researchers assessed the capability of commercial imagery to spectrally discriminate between coral, algae, and the near-surface seafloor. They compared environmental noise equivalent spectra of each sensor, retrieval of water depth, and benthic cover. In addition to employing imagery from the PlanetScope, WorldView-2, and WorldView-3 satellites, researchers used imagery acquired by the Portable Remote Imaging SpectroMeter (PRISM) airborne hyperspectral instrument. Imagery from WorldView-2 and -3 showed great promise for mapping coral reef ecology and provided 90-94% of the accuracy of the PRISM data at a finer spatial resolution at lower cost.

Researchers assessed the utility of imagery to map macroalgae and oil slicks in the Gulf of Mexico, the Caribbean Sea, East China Sea, and the Yellow Sea. The WorldView imagery showed potential in detection of unknown ocean surface features, which are speculated to be caused by aggregation of sea jellies. If confirmed, this may represent the ability to detect concentrations of jellyfish, whose changes over the long term are indicators of changes in the ocean's biological and chemical properties.

Researchers evaluated the utility of commercial imagery and quantified abundance and distribution of Submerged Aquatic Vegetation in nearshore coastal waters, and sea ice conditions in the Chukchi-Beaufort Sea region of the Arctic Ocean. The higher spatial resolution imagery from WorldView-2 and -3 proved adequate for mapping the percent cover of the submerged aquatic vegetation by expert analysts. Because the mapping was done on an image by image basis, the Maxar Technologies radiometric calibration was sufficient and no atmospheric calibration was required.

Finding 6: Quality of vendor supplied imagery and/or data

The quality of Maxar Technologies imagery has been evaluated by researchers with expertise in time series and trend analysis to assess the radiometric quality of imagery suitable for scientific research.

Radiometric Calibration

The radiometric stability of time series and trend analyses from WorldView-2 and -3 satellites in support of Earth science research and applications were analyzed. The calibration trends were characterized for imagery acquired over a quasi-stable desert Committee on Earth Observation Satellites (CEOS) calibration site (Libya-4). Both satellites showed radiometric calibration trends, with WorldView-3 being the more stable of the two. Trends in WorldView-2 were approximately twice as large as the calibration trends in MODIS Collection 5 data. MODIS calibration comparisons were used to bring the three sensors into close agreement within ±3%.

Planet

Finding 1: Accessibility

While the PIs were able to search and discover data without much difficulty, download of bulk data from the vendor archive was found to be moderately difficult. The vendor was responsive to these issues and made a concerted effort to resolve accessibility in a timely manner. As the CSDAP evaluation progressed, the vendor system capability to support bulk downloads improved.

Finding 2: Completeness and accuracy of metadata

The metadata accompanying the imagery did not fully conform to standards that the Earth science community is accustomed to. A few PIs found the metadata to be incomplete and inaccurate. Inaccuracies were related to cloud screening, geolocation, and calibration parameters.

Finding 3: User support services

The PIs found user support provided by the vendor helpful, informative, and delivered promptly. The vendor held multiple tutorials to assist in the use of Application Programming Interface (API), QGIS, and Planet Explorer tools. The PIs found the user documentation to be satisfactory. However, the vendor was unable to provide documentation that fully describes the methodology adopted for intercalibration of the constellation over time. The vendor is actively working on publishing this information.

Finding 4: Appropriateness of End User License Agreement for scientific research

The PIs found the EULA appropriate for evaluation, but license terms inhibited standard scientific collaboration. PIs expressed concerns regarding the terms and conditions of the EULA that prevented them from widely distributing derived products to the scientific community. Further restrictions on the ability to submit source data to journals to recreate experiments was noted. Restrictions related to sharing of imagery and data across U.S. federal agencies and partners were also found to be problematic.

Finding 5: Usefulness for science and applications

The utility of Planet imagery data differs among the ESD interdisciplinary science focus areas, as shown in the detailed descriptions below. In general terms, the usefulness of Planet data is high for small scale studies, but the application of data for regional to global long-term global studies is limited by availability of data for SkySat and calibration and geolocation for PlanetScope. To simplify the results of the evaluations, the following groupings are used: Atmosphere, Cryosphere, Land, and Water.

Atmosphere: Clouds and Aerosols

Researchers found commercial imagery to be potentially valuable for characterizing atmospheric aerosols at spatial and temporal resolutions that are substantially finer than what is currently available. Products derived from commercial imagery will complement and extend existing data products lines.

PIs found that PlanetScope imagery has sufficient radiometric quality for enabling the retrieval of Aerosol Optical Depth (AOD) at approximately 15-meter spatial resolution. They commented on the need for further research to understand and address issues associated with among-Dove radiometric calibration. These higher resolution AOD products will complement AOD products derived from multispectral imagery acquired by existing NASA/NOAA platforms.

Cryosphere: Snow and Ice

Researchers were able to use commercial imagery for quantifying the extent of melt water over Greenland ice sheets. Using stereo imagery, researchers were able to calculate surface elevation at 2 m horizontal resolution. They encountered a number of limitations, including absence of shortwave infrared (SWIR) bands, non-availability of suitable off-nadir viewing angles, reliable calibration, and accurate geolocation.

Researchers demonstrated significant potential using SkySat and RapidEye data to map ice sheet melt ponds and calculate melt pond volume at sub-weekly timescales. Researchers also evaluated stereo retrieval of elevation using Planet SkySat video and triplet stereo products for a range of targets, including snow-covered mountains, glaciers, forests, and salt flats. The team found that the stereo DEM accuracy and quality scaled with spatial resolution and was extremely useful. They were also successful in demonstrating the generation of more accurate DEMs over steep terrain using the multi-view stereo geometry provided by the SkySat satellites. The researchers noted that issues associated with PlanetScope Dove sensor calibration, geolocation accuracy, radiometry, and lack of cloud cover in the metadata hindered elevation retrievals in snow-covered regions because surface contrasts for snow and ice are low compared to other areas. Optical retrieval of snow and ice elevation is highly dependent upon surface feature identification between two satellite images.

Researchers developed workflows and image processing tools necessary for identifying icebergs in open water, where the background color has a radiometrically sharp contrast with icebergs. They were successful in detecting smaller icebergs off of Greenland. PlanetScope Dove Classic imagery over mélange was found to have poor radiometric contrast. The images appeared washed out, making it impossible to differentiate between sea ice, icebergs, and mélange in some cases. These issues were not present with data from PlanetScope Dove-R and RapidEye.

Researchers compared glacier extent and area estimates using imagery acquired by PlanetScope, RapidEye, and the NASA/USGS Landsat-8 satellites, and found the spectral contrast between clouds, ice, and snow provided by the Landsat Short-Wave InfraRed (SWIR) band to be critically important for remote sensing research that focuses on the cryosphere. Despite better spatial and temporal resolution provided by the PlanetScope and RapidEye constellations, the lack of a SWIR band is a significant limitation.

Overall, given the high spatial and temporal frequency of PlanetScope data, it was found to be very useful for tracking the rapid changes in the cryosphere.

Land: Agriculture, Forest, Urban

Researchers were able to generate multi-temporal maps of canopy chlorophyll, detect disturbances from selective logging, estimate planted wheat area in Pakistan, perform yield assessment of corn and soybean in the US, identify smallholder agriculture fields in Uganda, track seasonal changes in lake extent, track lake dynamics, and estimate methane flux. The Planet data allowed for accurate mapping of landslides and small and spatially-fragmented low-combustion and ephemeral burns. They found that despite the lower spectral resolution, the absence of a SWIR band, lower radiometric quality, and insufficient quality cloud data mask compared to other sensors, the PlanetScope imagery extended existing tropical forest monitoring capabilities.

The researchers showed that imagery from Planet's RapidEye constellation enabled the generation of multi-temporal maps of canopy chlorophyll at a spatial resolution that exceeds Global Climate Observing System (GCOS) Land Essential Climate Variables (ECV) resolution requirements by a factor of 10. The study demonstrated that high-resolution commercial imagery can serve as a valuable tool for: 1) upscaling leaf to canopy chlorophyll content, and 2) assessing the spatial variability in top-of-canopy chlorophyll content at an accuracy comparable to field observations.

PlanetScope imagery was successfully used to detect disturbance from selective logging and blowdowns where Landsat-8 data could not. Fire disturbance that impacted larger areas was detectable by both PlanetScope and Landsat-8. Imagery from Planet was highly advantageous for monitoring small scale changes in forest structure.

Wheat area estimates for Punjab, Pakistan produced using PlanetScope imagery were over 95% accurate, a 15-20% improvement over Landsat-8, which suffered from too coarse spatial resolution and inadequate temporal coverage. Planet data were found to be critical for identification of all disturbance events, recovery events, and quantifying carbon stocks where forest degradation is widespread, such as in the Republic of Congo.

Researchers used PlanetScope imagery and found it effective for tracking seasonal changes in lake extent, understanding lake dynamics, estimating methane flux, mapping river and lake ice, and analyzing burned and unburned areas in the boreal region. They commented that improvements in accessibility of data, accuracy of the cloud mask, and better radiometric resolution would further enhance the usefulness of the imagery.

Researchers assessed the utility of PlanetScope and RapidEye imagery by understanding, detecting, and accurately predicting landslides in support of disaster mitigation and response efforts. They were able to detect up to 94% more landslides compared to Landsat-8 and 74% more when compared to Sentinel-2. The researchers commented that access to commercial imagery supported rapid and more accurate mapping of landslides and the opportunity to create global landslide inventories from which to evaluate landslide models.

Researchers that used imagery from PlanetScope and SkySat for mapping agriculture, forest, and urban land use in Vietnam commented that large differences and edge effects in surface reflectance seriously limited their ability to create image mosaics. In addition artifacts related to smoke, haze, and the presence of clouds – including cirrus contamination – substantially reduced the volume of usable imagery.

The researchers found significant differences in derived surface reflectance and NDVI when comparing the same agricultural and open flood water sites from PlanetScope, Landsat-8, and Sentinel-2 imagery. For NDVI, the bias between PlanetScope and Landsat seemed to vary by overall green vegetation density and time of year. The researchers commented that while Planet data provided better temporal sampling, it exhibited a significant amount of among-satellite calibration uncertainty that limited its usability at the advertised repeat frequency.

The researchers found that the higher spatial and temporal resolution PlanetScope Dove imagery enabled improved mapping compared to Landsat-8 and Sentinel-2 for small and spatially-fragmented, low-combustion temperature, and ephemeral burns. Therefore, the use of PlanetScope Dove imagery has the potential to substantially improve quantification of global pyrogenic emissions. While PlanetScope Dove Classic imagery was found to be useful for visual interpretation, imagery from the PlanetScope Dove-R series of satellites provided improved burned/non-burned discrimination due to non-overlapping spectral band response functions. A SWIR band would provide additional burned area mapping capability.

Researchers evaluating the usefulness of commercial imagery for agriculture, such as crop type mapping and yield assessment of corn and soybean, found that while PlanetScope imagery was spectrally limited, the higher temporal resolution allowed a more accurate assessment of crop phenological stage, which is critical to the identification of the most suitable date for assessing corn and soybean yield. The imagery explained within-field yield variability for corn and soybean in the U.S. Midwest. It also allowed mapping of smallholder agriculture fields in Uganda and reduced bias in area estimates compared to those derived from moderate spatial resolution imagery. The imagery provided by vendors was not accompanied by a data quality layer related to clouds, shadows, or poor-quality pixels, such as those accompanying MODIS and Landsat data. The diversity of individual sensors makes uniform approaches to atmospheric correction difficult and needs to be addressed. The researchers commented that Planet imagery is neither radiometrically consistent across the constellation nor is the quality near what the investigators are accustomed to with the Landsat-8, Sentinel-2, and Terra/Aqua MODIS calibration characterizations.

Researchers found the NDVI derived from PlanetScope imagery over West Africa has a variance twice as large as the variance in NDVI derived over the region from MODIS. They commented that the utility of the PlanetScope constellation would be greatly enhanced if rigorously intercalibrated, allowing derivation of a global NDVI product, and that such capability will have substantial benefits for NASA's food security and carbon cycle research.

PIs using PlanetScope imagery were successful in mapping burnt areas and delineation of field borders for agriculture and forested areas in India. Using single-date 90% cloud free imagery from Planet, researchers were able to detect 5% more burnt area than with Landsat, and 9% more burnt area than with Sentinel-2. The researchers employed a more robust atmospheric correction algorithm. They commented that the higher temporal resolution PlanetScope imagery provided a significant advantage by allowing capture of transient biomass burning events more effectively.

Researchers assessed the value of PlanetScope imagery for extracting information about forest structure and disturbance history. They found that despite lower spectral resolution, no SWIR band, lower radiometric quality, and insufficient cloud masks, PlanetScope imagery extended existing tropical forest monitoring capabilities with higher spatial and temporal resolution compared to medium resolution imagery. They commented that PlanetScope imagery allowed them to better satisfy stakeholder needs, which requires better information on the drivers of forest degradation and loss, including fires, logging, and agricultural encroachment.

Researchers assessed the usefulness of PlanetScope imagery for stereo retrieval of surface height at 4-5 m horizontal spatial resolution. While they were successful in retrieving the surface height from the imagery, they emphasized the need for imagery at suitable off-nadir viewing angles, reliable calibration, accurate geolocation, and rigorous cloud clearing for DEM generation. The researchers also found the PlanetScope tools for interrogating the catalog to identify suitable image pairs for stereo processing to be ineffective.

Water: Lakes, Rivers, and Oceans

Researchers assessed the capability of commercial imagery to spectrally discriminate between coral, algae, and the near-surface seafloor. Researchers determined that Planet imagery was not well-suited

for the understanding of reef ecology. They were successful in mapping: macroalgae and oil slicks; flood extent in urban areas; ephemeral water bodies in Africa; and submerged aquatic vegetation in near-coastal waters.

Researchers assessed the utility of imagery to map macroalgae and oil slicks in the Gulf of Mexico, the Caribbean Sea, East China Sea, and the Yellow Sea. Despite problems associated with sensor calibration and the relatively low signal-to-noise ratio, researchers found imagery from PlanetScope to be effective in detecting and quantifying macroalgae, as well as differentiating oil emulsions from non-emulsions.

Researchers assessed the usefulness of PlanetScope imagery for identifying and monitoring ephemeral water bodies in West Africa. The higher spatial and temporal resolution imagery allowed researchers to map small water bodies that were previously not detectable with the available medium resolution imagery. This capability will assist pastoralists in West Africa to better guide their herds to water, increasing their resiliency to changes in climate.

Researchers successfully improved flood extent determinations in urban areas products using PlanetScope imagery. Errors in the European Copernicus Programme Sentinel-1 Synthetic Aperture Radar 10-20 m scale flood extent were striking when compared with 3-4 m imagery from PlanetScope. Compared to Landsat-8, PlanetScope imagery also provided more precise flood extent delineation due to higher spatial and temporal resolutions.

Finding 6: Quality of vendor supplied imagery and/or data

Researchers with expertise in radiometric calibration and geolocation accuracy were engaged to assess the radiometric quality of imagery suitable for scientific research. The details are presented below.

Radiometric Calibration

Researchers analyzed the radiometric calibration accuracy of PlanetScope imagery using 6 months of imagery over 67 land calibration sites. They concluded that PlanetScope radiometric calibration accuracy needs improvement to support robust scientific investigations. Each instrument needs to be characterized prior to launch, calibrated while in flight, and these calibrations should then be assessed independently throughout the instrument's lifetime. In-flight calibration should be achieved by a combination of an on-board system and/or vicarious calibration methods (lunar, cloud, Rayleigh scattering, pseudo-invariant calibration sites, etc.). It would be extremely helpful if calibration information and methods are made available to the scientific community.

Geolocation Accuracy

Researchers analyzed the positional accuracy of PlanetScope imagery against higher resolution imagery Maxar Technologies (QuickBird) imagery with known accuracy. The geolocation accuracy and apparent spatial resolution of PlanetScope imagery were found to be insufficient to support scientific analysis at the reported 3-4 m pixel resolution. Typically, geolocation accuracy for scientific research is set at less than 0.5 of the pixel resolution, with a goal of less than 0.2 of the pixel resolution. To ensure all images satisfy one single requirement, it is customary to use the worst scenario as the requirement. In this case, images over Australia had the largest standard deviation, of about 20 m. Therefore, the pixel size needs to be 40 m, which is 13 times that of PlanetScope's nominal pixel size. Images over Asia had the lowest standard deviation of about 2 m, necessitating a pixel size of 4 m, which is close to the

PlanetScope pixel size. For all other regions, pixel size needs to be at least 10 m, which is three times PlanetScope's nominal pixel size.

Spire

NASA acquired measurements from Spire Global's constellation, which receives signals transmitted by multiple Global Navigation Satellite Systems (GNSS), including the U.S. Navstar Global Positioning System (GPS) and Russia's GLObal NAvigation Satellite System (GLONASS) constellations. Although not used in the evaluation, the EU constellation Galileo is also discussed here. The GNSS constellations are transmitting systems, whereas Spire, and other similar constellations, are signal receiving systems.

Finding 1: Accessibility

At the time of the data buy, there was not a suitable location to place and distribute the Spire data. Since the data volume was small in terms of disk and bandwidth requirements, the data were downloaded to NASA's GSFC and staged for the PIs by leveraging resources within GSFC's Global Modeling and Assimilation Office (GMAO). Orders were submitted manually, working directly with Spire Global. Several PIs noted that Spire was generally amenable to specific requests, including providing a catalog to PIs so specific profiles meeting certain criteria could be selected and purchased.

Finding 2: Completeness and accuracy of metadata

Generally, the metadata was found to be complete. In some cases, it was found to be either poorly documented or lacking in numerical precision (i.e., one number was found to be truncated to 8-bit along the processing chain), which affected the accuracy of the observables.

Finding 3: User support services

When issues arose, Spire was generally found to be responsive. Specific issues were directly addressed between the PIs and Spire, resulting in a reprocessing and redelivery of the data by Spire.

Finding 4: Appropriateness of End User License Agreement for scientific research

The PIs found the EULA appropriate for evaluation, but license terms inhibited standard scientific collaboration. First, there were concerns regarding public archiving of data regarding publication requirements. Second, there were concerns regarding the distribution of 'derivatives' – specifically how the EULA would limit the inclusion of Spire observations into data products (e.g., incorporation into an atmospheric reanalysis). Restrictions related to sharing of imagery and data across the U.S. federal agencies and partners were also found to be problematic.

Finding 5: Usefulness for science and applications

The utility of the Spire observations is reported as a function of three thematic areas: Ocean, Atmosphere, and Space Weather. The projects relevant to the Atmosphere and Ocean thematic areas were funded via the Earth Science Division and the Space Weather project was funded via the Heliophysics Division. The details are presented below.

Ocean

The project that focused on Spire GNSS-Reflectometry (GNSS-R) measurements over the ocean found them to be suitable for retrieving sea surface height (SSH) for ocean altimetry applications. The data showed phase coherency for low grazing angle reflections, though the relative volume of these observations was small – about 4% of the total ocean GNSS-R measurements considered. With these

valid data, the project was able to obtain preliminary SSH information from these data that showed good agreement with a mean sea surface (MSS) model derived from traditional radar altimeter satellites with deviations in the expected range for ocean dynamic processes. The SSH precision is estimated as 2.5 cm for 1-second averages. The SSH accuracy will require more evaluation but is better than 10 cm.

Atmosphere

Three projects evaluated the Spire GNSS-Radio Occultation (RO) observations. Of the two PIs reporting, both found the Spire data to be consistent with similar RO receiving systems. Spatially, the data were found to be largely complementary to similar observing systems (e.g., Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC)/COSMIC-2). Data acquired from the Spire constellation allowed for observation of regions of the globe otherwise unobserved by RO – specifically, by filling gaps between the orbits of the baseline radio occultation observing system. The Spire constellation observing strategy results in a number of orbits that sample data-void regions globally, such as areas unobserved by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Metop satellites, which are in fixed sun-synchronous orbits. For the Pilot study period, the Metop satellites are the largest source of data, though since that period, the COSMIC-2 constellation has launched into low inclination orbits and will improve sampling of the tropics. The PIs noted the Spire constellation improves the diurnal sampling globally via RO.

In terms of observation quality, the biases and variability of the Spire data were found to be consistent with other RO observing systems. This was diagnosed by directly considering the Spire-processed Level 2 data and by considering the Level 1 data processed to Level 2 products by the evaluation team. More tropospheric biases were noted in the RO measurements derived from the GLONASS constellation than those from GPS and QZSS, a regional GNSS owned by Japan, both in the Level 1 and Level 2 data. Furthermore, these data were seen to be consistent with other RO observing systems in terms of their impact on numerical weather prediction. The initial results illustrated that the observations carried a similar per-observation impact on reducing the 24-hour short-term forecast error as other RO observing systems, and that this impact scaled with observation count. Recently, Spire has added RO data measured from the Galileo satellite system, but these data were not assessed in this study.

Additionally, the data were considered in meteorological process studies. The observations were found to consistently measure the height and temperature of the cold point tropopause. They were also found to be effective in retrieving the height of the planetary boundary layer, as their penetration depths were assessed as being particularly good. In fact, they were determined to exceed those of heritage RO observing systems (e.g., COSMIC-1) and as comparable to those of modern RO science missions (e.g., COSMIC-2).

Space Weather

One project focused specifically on the Spire Precise Orbital Determination (POD) measurements and the Spire near-continuous attitude quaternions. Using these observations and drag coefficients determined from descoped computer-aided design models of the Spire satellites, the project showed that the day-to-day variability of thermospheric density can be readily extracted. It is noted that validation with other data sources is problematic due to the lack of reliable sources during the assessment period. While the technique struggled with lower duty cycles early in the assessment

period, the atmospheric drag signal is clearly present in the POD data thereafter. The constellation approach is notable, as the timescales of interest in the upper atmosphere are on the order of 1 hour to several days. Therefore, these sampling approaches will be important in the future to extract upper atmospheric densities on a sub-daily cadence.

6 Evaluation Results and Recommendations

End User License Agreements

NASA PIs found the EULAs appropriate for evaluation, but license terms inhibited standard scientific collaboration. PIs expressed concerns regarding the terms and conditions of the EULA that prevented them from widely distributing derived products to the scientific community. Further restrictions on the ability to submit source data to journals to allow the recreation of experiments were noted. Restrictions related to the sharing of data across U.S. federal agencies and partners were also found to be problematic. Additionally, each vendor's EULA had slightly different terms and conditions. This created additional complexities and cumulative restrictions for PIs that used data from more than one vendor.

Finding the right balance between open science and the commercial viability of small satellite companies is difficult. Good scientific practice requires open cross-organizational collaboration and the ability to publish in scientific journals and reproduce scientific results. However, providing data openly to the science community is not practical for commercial companies, as it reduces revenue sources. NASA and commercial partners need to work together to address these concerns. A vibrant, self-sustaining, innovative commercial marketplace of small satellite data providers is beneficial to NASA science; however, equally beneficial are the investments NASA makes in understanding, improving, and developing derived products from commercial data. Vendors will ultimately benefit from the basic research investments by NASA as scientific results are made public.

Recommendations: The first recommendation is to develop a standard EULA for data procured by the CSDAP program. A standard EULA will provide a uniform set of terms and conditions for researchers and vendors to follow while protecting commercial rights to data. This standard EULA will have the following principles:

1) Data will be made available only to the NASA scientific community (NASA government employees, researchers on or participating in active NASA grants, and NASA funded contractors and related entities);
2) Data and derivatives will only be available for scientific use – commercial and operational use will be prohibited;
3) Derivative products can be made available to the scientific community only for scientific use; and
4) There will be no restrictions on publication of scientific results, including providing source data required by some publishers, in journals or other established channels of public dissemination of scientific information.

The second recommendation is to increase coordination among U.S. federal agencies, with the objective of developing a common commercial data licensing framework and sharing lessons learned from existing programs designed to acquire data from commercial operators.

Maxar Technologies

NASA PIs were able to evaluate a variety of data from Maxar Technologies platforms for existing research activities. The characteristics of data that enabled successful outcomes of the research included high spatial resolution, availability of SWIR bands, longer temporal coverage, and being well-calibrated. Out of 18 PIs, 12 recommended continuing access to all of the sensor platforms currently offered by Maxar Technologies.

Recommendation: High utility of Maxar Technologies data was demonstrated for detection, segmentation, and classification of features for NASA research and application activities spanning multiple thematic areas. In contrast, time series-based studies were limited due to intermittent coverage over study areas. Due to high utility based on their very high spatial resolution, availability of SWIR bands, and mature calibration, the recommendation was to continue utilizing the NGA NextView program to obtain data currently collected by Maxar Technologies at no cost to NASA. It is also recommended that Maxar Technologies continue to improve data with respect to 1) time varying calibration coefficients, 2) cross-calibration between images, 3) more acquisitions using the SWIR bands.

Planet

NASA PIs were able to evaluate all data sources from Planet platforms (PlanetScope, SkySat, and RapidEye) within existing research activities. The data characteristics most valuable to researchers included high spatial resolution and, in particular, the nearly daily repeat frequency available from PlanetScope. Radiometric and geometric attributes need to be improved. A total of 22 out of 28 PIs recommend continued access to Planet data. Additionally, continued improvement of direct PI data access/download is warranted.

PlanetScope Recommendation: The utility of PlanetScope to NASA research and application activities was demonstrated. There were high utility scores for single date imagery data analysis, but low utility for time series analysis because of issues with calibration and geolocation. The overall utility was determined to be sufficient to continue the procurement of data with the following requirements:

- Provide global unlimited access to PlanetScope data
- Improve data access capabilities
- Improve metadata and share detailed calibration information
- Improve calibration and geometric precision and accuracy
- Modify EULA to allow for publication of scientific results and distribution of derivative products to scientific users

RapidEye Recommendation: RapidEye was demonstrated to be of high utility, not only due to its high spatial and temporal coverage, but also due to its footprint compared to PlanetScope. Overall assessment was in favor of the continued purchase of RapidEye data, with the understanding that Planet will establish quality baselines for the data products. However, during the evaluation, Planet Labs announced plans to decommission RapidEye satellites in 2020.

SkySat Recommendation: SkySat provides the unique ability to task the constellation of sensors, which is valuable for multi-view stereo acquisition and rapid response. The demonstrated utility of SkySat is determined to be adequate to continue the procurement of data with the following requirements:

- Improve cloud cover detection

- Improve band spectral response functions and the add quantizing levels
- Improve documentation
- Modify the EULA to allow for publication of scientific results and distribution of derivative products to scientific users

Spire

Of the five evaluations that specifically targeted the Spire data products, all indicated the Spire data were suitable for continued scientific use in NASA-funded projects, though the PIs noted a few key points for improvement. Additionally, the mechanism for accessing and ordering from Spire's data catalog needs to improve data discovery.

Recommendation:

- Provide global unlimited access to Spire data to support global scientific research
- Expand sources of RO observations to other constellations
- Develop a data catalog and improve metadata
- Modify EULA to allow for publication of scientific results and distribution of derivative products to scientific users

7 Conclusions

Over the course of a year, 41 PIs representing each of the six R&A science focus areas, Applied Science program elements, and one project from the Heliophysics Space Weather Program evaluated data from Planet, Maxar Technologies, and Spire. A significant majority of these evaluations demonstrated the usefulness of commercial data and imagery for advancing scientific research and applications. However, PIs encountered numerous limitations that either diminished the usefulness (e.g., calibration and geolocation) and/or increased the amount of work needed to access, preprocess, and analyze data (e.g., download services, documentation, metadata, etc.). Additionally, the restrictive nature of the EULAs made standard scientific collaboration difficult and must be addressed in future data purchases. Overall, the utility of the evaluated data outweighed the difficulties encountered, and NASA will work with vendors on maintaining access to data for NASA science and applications while addressing the issues encountered.

Based on the success of this pilot program, NASA has established the Commercial SmallSat Data Acquisition Program to: 1) Establish continuous and repeatable processes to onramp new commercial data vendors and evaluate data for their potential to advance NASA's Earth science research and applications activities; 2) Enable the sustained use of purchased data for broader use and dissemination by the NASA scientific community; 3) Ensure long-term data preservation through the establishment of data management processes and systems to support rapid evaluation, access, and distribution of purchased data, and long-term access to purchased data for scientific reproducibility; and, 4) Coordinate evaluation and scientific use with the European Space Agency (ESA) as part of the Joint Program Planning Group activities for data from third party missions. The third onramp opportunity for new companies to be evaluated by NASA under the CSDAP will be in the fall of 2020. Updates and details are available through the EarthData website (https://earthdata.nasa.gov/esds/small-satellite-data-buy-program).

Appendix A. Listing of Pilot Research Projects

Research using Planet data:

- Assessing Planet Imagery for the Arctic-Boreal Vulnerability Experiment (ABoVE) (PI: Elizabeth Hoy, SSAI/NASA GSFC)
- Monitoring and Projecting Environmental Change in Fragmented Tropical Forest Landscapes (PI: Michael Wimberly, University of Oklahoma)
- Feasibility of Planet Data for Rapid Disaster Response (PI: Batuhan Osmanoglu, NASA GSFC)
- Exploring the Use of Planet Data for Monitoring High Resolution Forest Disturbance (PI: Laura Duncanson, University of Maryland)
- Evaluation of the Potential to Use Commercial High-Resolution Multispectral Imagery for Monitoring Small Water Bodies in West Africa (PI: Ashutosh Limaye, NASA MSFC)
- Potential Air Quality Application of Planet Data (PI: Tracey Holloway, University of Wisconsin)
- Mapping the Missing Millions: Developing a Global Database of Informal Settlement Location, Schema, and SDG indicators (PI: Jamon Van Den Hoek, Oregon State University)
- Burnt Area Mapping in South/Southeast Asia using Multi-Satellite and Very High Resolution Planet data (PI: Krishna Vadrevu, NASA MSFC)
- Controls on Iceberg Distribution Around Greenland (PI: Leigh Stearns, University of Kansas)
- Tropical Glacier Area Mapping: Comparison for Landsat-8, PlanetScope and RapidEye (PI: Compton Tucker, NASA GSFC)
- Assessment of High Resolution PlanetScope Imagery for Aerosol Remote Sensing Applications (PI: Jaehwa Lee, NASA GSFC)
- Assessing Crop Type, Extent, Production and Forest Disturbance in Asia and Africa (PI: Matthew Hansen, University of Maryland)
- Comparison of Normalized Difference Vegetation Index (NDVI) derived from MODIS and PlanetScope (PI: Compton Tucker, NASA GSFC)
- Meltwater on the Greenland Ice Sheet during a Record Melt Season (PI: Rajashree Tri Datta, NASA GSFC)
- Evaluation of PlanetScope imagery for global DEM generation (PI: M. J. Noh, Ohio State University)

Research using Maxar Technologies data:

- Evaluation of Commercial Satellite Data for Essential Water Variables: Snow Cover Fraction and Annual Minimum Snow and Ice Extent (PI: Karl Rittger, University of Colorado)
- Precipitation and Glacier Change in High Mountain Asia Over the Modern Era (PI: Summer Rupper, University of Utah)
- Evaluation of Commercial Satellite Data Products for Cloud Remote Sensing (PI: Kerry Meyer, NASA GSFC)
- Evaluation of Commercial Satellite Observations for Coastal Ecosystem Science Studies (PI: Dirk Aurin, NASA GSFC)

Research using Spire data:

- The Use of Spire Radio Occultation Measurements in the GEOS Atmospheric Data Assimilation System (PI: Will McCarty, Global Modeling and Assimilation Office/NASA GSFC)
- Development of Simulation and Retrieval Techniques for Precipitation Effects on GNSS Occultation Signals (PI: Jennifer Haase, Scripps Institution of Oceanography/UC San Diego)
- Data Processing and Scientific Evaluation of Spire GNSS RO Data for the NASA Commercial Data Buy Program (PI: Bill Schreiner, UCAR COSMIC Program)
- Phase-Delay Altimetry from Reflected GNSS Signals for Resolving Mesoscale Ocean Circulation Features (PI: R. Steven Nerem, University of Colorado)
- Spire POD/Neutral Density Assessment (PI: Eric Sutton, Space Weather Technology, Research, and Education Center/Univ. of Colorado)

Research using Planet and Maxar Technologies data:

- Augmentation to Disaster Response and Coordination Activities at Marshall Space Flight Center to Support NASA Commercial Data Buy Pilot (PI: Andrew Molthan, NASA MSFC)
- Evaluation of Commercial High-Resolution Satellite Imagery for Coral Reef Ecology (PI: Eric Hochberg, Bermuda Institute of Ocean Sciences)
- Distribution and Abundance of Pelagic Sargassum and their Linkage with Environmental Changes in the Intra-Americas Sea and Tropical Atlantic: an Interdisciplinary Assessment (PI: Chuanmin Hu, University of South Florida)
- Multi-Sensor Geohazard Assessment Along Key Transportation Corridors in High Mountain Nepal (PI: Dalia Kirschbaum, NASA GSFC)
- Prototyping Multi-Source Land Imaging Canopy Chlorophyll for the Assessment of Vegetation Function and Productivity – Evaluation of High Resolution Commercial Data (PI: Petya Campbell, University of Maryland, Baltimore County/NASA GSFC)
- NASA NeMO-Net – The Neural Multimodal Observation & Training Network for Global Coral Reef Mapping (PI: Researcher, NASA Laboratory for Advanced Sensing)
- High Spatial Resolution, Commercial Satellite Data Applied to the Study of LCLUC on Islands (PI: Stephen Walsh, University of North Carolina)
- Land-Cover/Land-Use Change in Southern Vietnam Through the Lenses of Conflict, Religion, and Politics, 1980s to Present - Augmentation to Evaluate Commercial Remote Sensing Data (PI: Jessica McCarty, Miami University)
- Environmental Determinants of Enteric Infectious Disease: a GEO Platform for Analysis and Risk Assessment—Commercial Data Supplementary (PI: Benjamin Zaitchik, Johns Hopkins University)
- Africa Burned Area Product Generation, Quality Assessment and Validation – Demonstrating a Multi-Source Land Imaging (MuSLI) Landsat-8 Sentinel-2 Capability (PI: David Roy, Michigan State University)
- Commercial Imagery for Water Quality (PI: Blake Schaeffer, Environmental Protection Agency)
- Stereo2SWE: Regional Snow Depth and SWE from Sub-Meter Optical Satellite Stereo DEMs (PI: David Shean, University of Washington)
- Quantification of Blue Carbon Burial in Seagrass Ecosystems (PI: Richard Zimmerman, Old Dominion University)

- Combined use of VHR WorldView-2/3 and Planet datasets for agricultural monitoring (PI: Sergii Skakun, University of Maryland)

Research using Maxar Technologies, Planet, and Spire data:

- Integration of Altimeter Data from ICESat, IceBridge, CyroSat-2 and ICESat-2 – Mathematical Approaches and Applications to Glacial Change (PI: Ute Herzfeld, University of Colorado)

Calibration and Geolocation assessments:

- Evaluate the calibration of Dove and Dove-R (VHR) satellite data from the PLANET constellation (PI: Eric Vermote, NASA GSFC)
- PlanetScope Imagery Geolocation Accuracy Assessment (PI: Robert Wolfe, NASA GSFC)
- Calibration Trend Analysis of Maxar Technologies Imagers (PI: Alexei Lyapustin, NASA GSFC)