CAMPAIGN

GOOD EARTH

GAP ANALYSIS REPORT

CASIS™

Campaign Good Earth: Gap Analysis

Prepared for:

Center for the Advancement of Science in Space (CASIS)
6905 N. Wickham Road, Suite 500, Melbourne, FL 32940
www.iss-casis.org

Prepared by:

HySpeed Computing

James Goodman
HySpeed Computing
PO Box 431824 Miami, FL 33243
jgoodman@hyspeedcomputing.com
hyspeedcomputing.com

Study completed November 2015

TABLE OF CONTENTS

EXECUTIVE SUMMARY

INTRODUCTION

The objective of this analysis is to research and identify informational and technological gaps in remote sensing capabilities on the International Space Station (ISS) so that CASIS can plan, resource, and prioritize an engagement and project selection strategy for campaign Good Earth. As such, this analysis provides the information necessary to develop criteria for selecting and prioritizing ISS remote sensing projects. The end of this Executive Summary presents recommendations for achieving these objectives.

The report is organized into the following sections:

ISS Platform. Provides an overview of ISS remote sensing capabilities, identifies the advantages and limitations of the ISS for Earth observation, specifies the available internal and external payload mounting locations, describes the NASA payload selection and prioritization process, and lists all past, current and planned Earth observation missions on the ISS.

Remote Sensing Science Data. Specifies resources for accessing archived remote sensing data from NASA and other organizations, and identifies missions with the highest potential value for use in commercial applications.

Sensor Technologies. Provides descriptions of the most promising near-term sensor opportunities, which include hyperspectral, thermal, LiDAR, and synthetic aperture radar (SAR) imaging systems, and suggests an ideal integrated sensor suite based on these instruments, identifies data fusion opportunities and describes innovative and supporting sensor technologies.

Points of Contact. Lists individuals and companies relevant to campaign Good Earth, including contacts at NASA, and commercial companies involved in Earth observation, sensor development, data processing, and other supporting remote sensing technologies.

CAMPAIGN GOOD EARTH

From the CASIS Good Earth Campaign Overview, the mission of campaign Good Earth is:

“Maximizing International Space Station remote sensing opportunities for the good of humanity.”

“Good Earth is a CASIS-sponsored campaign that builds on existing and planned International Space Station (ISS) U.S. National Laboratory remote sensing capabilities to identify and attract commercial and non-commercial users to evaluate technologies and data product concepts that expand commercial markets, meet humanitarian needs, and provide educational enrichment.”

“The ISS National Laboratory is an effective low Earth orbit remote sensing and technology development platform that covers approximately 90% of the Earth’s population every 90 minutes.”

“Good Earth provides a process to:

- Identify technologies with broad benefit
- Explore the commercial potential of humanitarian decision support tools
- Evaluate algorithms and applications using NASA Science Data
- Engage commercial, humanitarian, and science, technology, engineering, and math (STEM) organizations
- Expose ISS National Lab to a broad audience”

RECOMMENDATIONS

The remote sensing industry is currently experiencing a remarkable transition point in its history, whereby the volume, extent, and scope of imaging data is expanding at an unprecedented rate. Although remote sensing data services were previously the domain of governments and large corporations, image acquisition and processing is increasingly being diversified across a broad range of scientific and commercial service providers. This includes government and commercial satellites, instruments on the ISS, constellations of small satellites, and piloted and unpiloted airborne imaging sensors. From a market viewpoint, the democratization of Earth observation is happening now, the rate of progress and investments in this industry are increasing rapidly, and opportunities abound throughout the industry. For example, consider the recent emergence of companies such as Skybox Imaging, Planet Labs, BlackSky Global, Urthecast, and OmniEarth, all of which are developing constellations of low-cost Earth-imaging satellites (and note that the last three of these only just announced their plans in the past year). Also consider the impending onset of commercial drone usage in the U.S. and the increasing number of CubeSat deployments. As this data-intensive market and commercial motivation to develop more sophisticated analysis capabilities continue to grow, competition in sensor technologies is expected to become increasingly relevant. Additionally, as the current multispectral market becomes saturated (or at least increasingly competitive), companies will be looking for different or next generation technologies to provide them with a competitive edge in the Earth observation market. Campaign Good Earth can make significant impact in this domain by promoting and expanding utilization of the ISS as a technology demonstration platform and unique resource for exploring data fusion opportunities.

Based on the Gap Analysis presented in this document, the following is a summary of recommendations for further engaging the remote sensing community, expanding infrastructure capabilities, and increasing utilization of the ISS for Earth observation. The report that follows provides details and further recommendations.

- Establish an Implementation Partner Program for businesses interested in deploying their technology to the ISS, but who require assistance with developing hardware interfaces, completing control documents, and navigating the flight readiness engineering and safety review processes. The intent is to partner companies who have expertise in sensor technologies, but not space flight, with companies who have significant experience in both space flight and sensor integration on the ISS (e.g., Teledyne Brown Engineering, NanoRacks, Urthecast, and Boeing). The program will create additional opportunities both for aspiring and established space companies.

- In the interest of exploring data fusion and instrument cross-calibration opportunities, sensor selection and mounting location should take advantage of the unique ISS capability of having multiple co-located sensors concurrently observing the same location on the Earth's surface. When feasible, such opportunities can be optimized by strategically selecting sensors that complement those already on station or others being deployed in the same timeframe.

- Expand the descriptions of the ISS Facilities & Hardware presented on the ISS U.S. National Laboratory web portal (http://www.spacestationresearch.com/) to specify the capabilities and characteristics of each type of payload mounting points, using data, photos, and visualizations available from NASA and CASIS, and the information contained in this document. It would also be informative to include an overview graphic of the ISS, ideally an interactive one, that indicates each mounting point's location. A good source for much of this information is the recently released NASA's External Payloads Proposer's Guide to the International Space Station, available at: http://espd.gsfc.nasa.gov/isseppg/GSFC_420-01-09_ISS_ExtPL_Proposers_Guide_Ch01.pdf.

- Develop a relational database of past, current, and planned Earth observation sensors (or a subset of those sensors with strong potential for commercial application), both on the ISS and free-flyers. The database should be correlated with instrument type, measurement capabilities, data archive location, and relevant applications. This can be accomplished in collaboration with ongoing work being conducted by NASA (e.g., refer to the information available online at the NASA/JSC Earth Science & Remote Sensing Unit website: http://esrs.jsc.nasa.gov/). The resulting database can then be shared via the ISS U.S. National Laboratory web portal.

- Sensor selection should be open-minded to all promising and innovative technologies, but as indicated in the report by McKinsey & Company, the overall portfolio should focus on hyperspectral, LiDAR, SAR, and thermal sensor technologies. These are mature sensor technologies in airborne remote sensing, and are thus well positioned for the transition to space. And from the market perspective, these technologies also represent the most significant near-term potential for use in commercial applications.

- One exception to the above categories is consideration of a Landsat/Sentinel/WorldView-3 type multispectral sensor to take advantage of the unique revisit frequency and acquisition times of the ISS as a complement or data fusion option for commonly utilized sun-synchronous sensors.

- To facilitate greater numbers of sensors and greater spatial coverage of high data volume sensors, ISS infrastructure investments should explore new technologies and opportunities to expand ongoing NASA efforts to increase the station's data downlink capacity.

- As supporting technologies, additional investments should include innovative solutions for computing and image processing, such as onboard data compression, quality control, and real-time product generation, as well as ground-based cloud computing, high-performance computing, and data distribution.

ISS PLATFORM

ISS OVERVIEW

The International Space Station (ISS) is a manned space station in low Earth orbit that serves as an orbiting research laboratory, testbed for conducting space science, technology demonstration platform, and proving ground for space exploration. This remarkable platform is a testament to human ingenuity and innovation. Research conducted on the ISS spans a vast array of scientific disciplines, including biology, human physiology, physics, astronomy, meteorology, drug discovery, materials science, and Earth observation. The ISS is also an exceptional demonstration of multinational partnership involving the National Aeronautics and Space Administration (NASA), Canadian Space Agency (CSA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA), Russian Federal Space Agency (Roscosmos), and the Italian Space Agency (ASI).

Some basic statistics on the ISS:[1]

- The ISS is the largest ever human made object to orbit Earth. Current mass is 410,501 kg (905,000 lbs), pressurized volume is 916 m3 (32,348 ft3), and size is approximately 95 m (311 ft) by 59 m (193 ft).

- Assembly of the ISS took 13 years, beginning in 1998 and completing in 2011, requiring 36 Space Shuttle assembly flights and five Russian launches.

- The ISS currently houses six crew members, with plans to add an additional crew member in the near future.

- The ISS offers a broad array of internal and external facilities for conducting research in microgravity and the space environment, including the ability to leverage crew interaction for performing experiments.

- Station resupply is currently accomplished using the Russian Progress and Soyuz vehicles, the Japanese H-II Transfer Vehicle (HTV), and commercial vehicles from SpaceX (Dragon) and Orbital ATK (Cygnus). Retired vehicles that were previously used include the Space Shuttle and European Automated Transfer Vehicle (ATV).

[1]*Reference Guide to the International Space Station, Utilization Edition, July 2015*

- The ISS orbits at an altitude from 350 to 455 km (217 to 283 miles) above sea level, with an orbital inclination of 51.6 degrees. This orbit covers approximately 90% of the Earth's populated area every 90 minutes, with repeat tracking over the same location every three days and repeat lighting conditions every 90 days.[2]

From the International Space Station Benefits for Humanity publication:

"The International Space Station (ISS) is a unique scientific platform that enables researchers from all over the world to put their talents to work on innovative experiments that could not be done anywhere else. Although each space station partner has distinct agency goals for station research, each partner shares a unified goal to extend the resulting knowledge for the betterment of humanity. We may not know yet what will be the most important discovery gained from the space station, but we already have some amazing breakthroughs.

"In the areas of human health, innovative technology, education and observations of Earth from space, there are already demonstrated benefits to people back on Earth. Lives have been saved, station-generated images assist with disaster relief, new materials improve products, and education programs inspire future scientists, engineers and space explorers.

"[Recently], a new constituency has developed, one that is using the ISS in a totally different fashion—to develop a commercial market in low-Earth orbit. From pharmaceutical companies conducting commercially-funded research on ISS, to private firms offering unique research capabilities and other services, to commercial cargo and crew, the ISS is proving itself to be just as adaptable to new business relationships as it has been for a broad diversity in research disciplines.

"All [these scientific, technological and educational accomplishments] serve as examples of the space station's potential as a groundbreaking research facility. Through advancing the state of scientific knowledge of our planet, looking after our health, developing advanced technologies and providing a space platform that inspires and educates the science and technology leaders of tomorrow, these benefits will drive the legacy of the space station as its research strengthens economies and enhances the quality of life here on Earth for all people."

ADVANTAGES AND LIMITATIONS FOR REMOTE SENSING

The majority of space-based remote sensing instruments are located on free-flying satellites, predominantly in either sun-synchronous polar-orbiting low Earth orbit or geosynchronous high Earth orbit. With a history dating back to the 1960s and 1970s, this paradigm has long been the norm for operational Earth observing satellites. As a result, given the ISS orbital inclination and its inherent orbit idiosyncrasies (i.e., changes in altitude and attitude), the remote sensing community was initially slow to adopt the ISS as a viable platform for Earth observation. However, the value of the ISS for remote sensing has now become much more widely recognized, particularly for technology demonstration and sensor development projects, and competition for its use has increased significantly.

Advantages of ISS as a remote sensing platform:

- ISS spacecraft infrastructure is extensive and robust; no need to develop a satellite bus.
- ISS provides access to power, communications, and data downlink.
- Multiple mounting locations and configurations are available for different sensor requirements.
- Crew is available to interact with and repair instruments.
- Instruments can be returned to surface for post-mission analysis.
- Orbit provides unique views, lighting conditions, and times-of-day for image acquisitions.

[2] *International Space Station Researcher's Guide to Earth Observations*

- Ideal platform for technology demonstration and development prior to deploying long-term free-flyer missions.

- Station internal resources provide capacity for onboard processing.

- Unique opportunities for data fusion facilitated by co-mounting sensors on same platform.

Because this analysis focuses on identifying informational and technical gaps in ISS remote sensing capabilities, the list of limitations that follows includes additional discussion on the relative impact of each item and suggestions on how it can be addressed:

- Perceived barriers regarding sensor deployment, integration, and operation. This is an information gap, where new users may be hesitant to pursue ISS options due to a lack of knowledge regarding capabilities, available documentation, and opportunities for support. This can be addressed in part by expanding the information presented on the ISS National Lab web portal (http://www.spacestationresearch.com/).

- Orbit offers irregular revisit times, views, and lighting conditions. For some users the orbit characteristics are seen as a limitation, but for others they are considered an advantage. Except for situations where the orbit is at odds with actual mission requirements, this limitation can be addressed by continuing to inform users of the advantages and opportunities that the ISS and its orbit offer for remote sensing

- Orbit irregularities for debris avoidance, altitude maintenance, and other maneuvers. These are unavoidable limitations associated with standard ISS operations, and the message for users is that the overall advantages outweigh the disadvantages of these brief disruptions in the orbit.

- Orbit is not completely global; polar regions not covered. This is only relevant to missions with high-latitude requirements, and is not addressable unless options exist for such missions to utilize lower latitudes as a technology demonstration opportunity prior to deploying a polar orbiting free-flyer.

- Additional requirements for crew and station safety. As with the orbit irregularities, these are unavoidable limitations associated with standard ISS operations. The message for users is that the overall advantages outweigh any additional requirements associated with crew and station safety.

- Increasing competition for a limited number of mounting points. From both the research and commercial perspectives, this limitation actually validates the value of the ISS as a remote sensing platform. However, it also means that unless additional mounting points are added, the incentive for new users to consider utilizing the ISS is reduced.

- Downlink capacity is limiting for high data volume sensors. This is also a common limitation for free-flyers and thus not unique to the ISS. Nonetheless, although providing unlimited downlink capacity is not a viable option, given the Good Earth objective to increase utilization of the ISS for remote sensing, expanding the downlink capacity is a logical step for reducing data volume limitations.

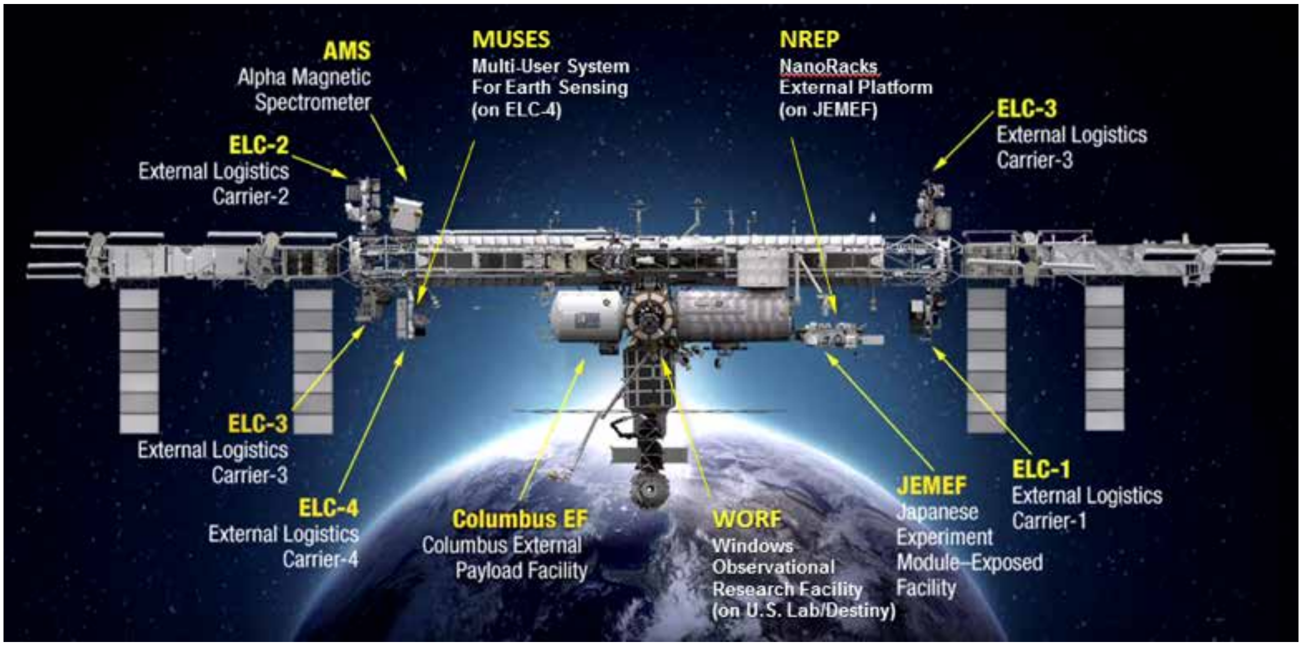
- Hardware and financial risks associated with launch and deployment scheduling, mounting point availability, and launch failures. This is a valid concern, but risk is an inherent aspect of working in the space industry. Additionally, given the advantages of the ISS and the launch support being provided, this risk is substantially reduced, particularly in comparison with launching free-flyer satellites. Managing concerns about risk can be addressed by acknowledging that certain risks exist and providing information on how CASIS, NASA, and prospective users can work together to reduce these risks.

- Uncertainties related to the expected life cycle of the ISS. This is relevant for deploying long-term missions on the ISS, but given current plans to keep the ISS operational until at least 2024, there is ample opportunity within this life cycle for both medium- and short-term technology demonstration missions, which is one of the real strengths of the ISS platform.

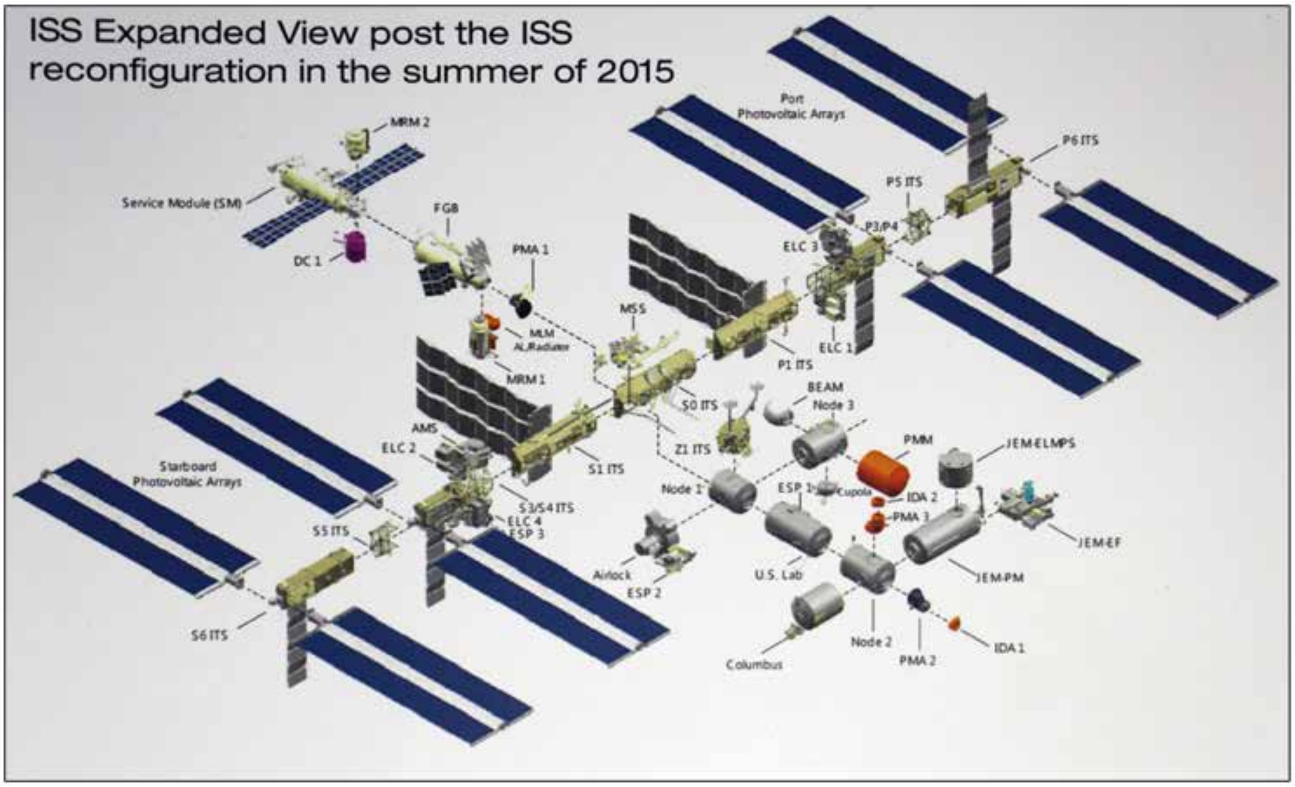
As mentioned above, despite some of its limitations, and given its many advantages, the ISS is increasingly being utilized as an effective platform for remote sensing. In addition to research sensors from NASA and other space agencies, this increase also includes new market development and commercial prospecting, such as the Multi-User for Earth Sensing (MUSES) platform from Teledyne Brown Engineering and the NanoRacks External Platform (NREP) from NanoRacks, which are attracting new customers by providing ISS-based sensor platforms as a service. Furthermore, CASIS and NASA have lowered many of the entry barriers for deploying and operating a remote sensing instrument on the ISS. Given this progress and the rise of the emerging space economy, which is democratizing access to space, it is expected that these trends will continue. There will be an increasing demand for utilization of the ISS for remote sensing, both from the research community and the commercial space industry.

PAYLOAD PLATFORMS

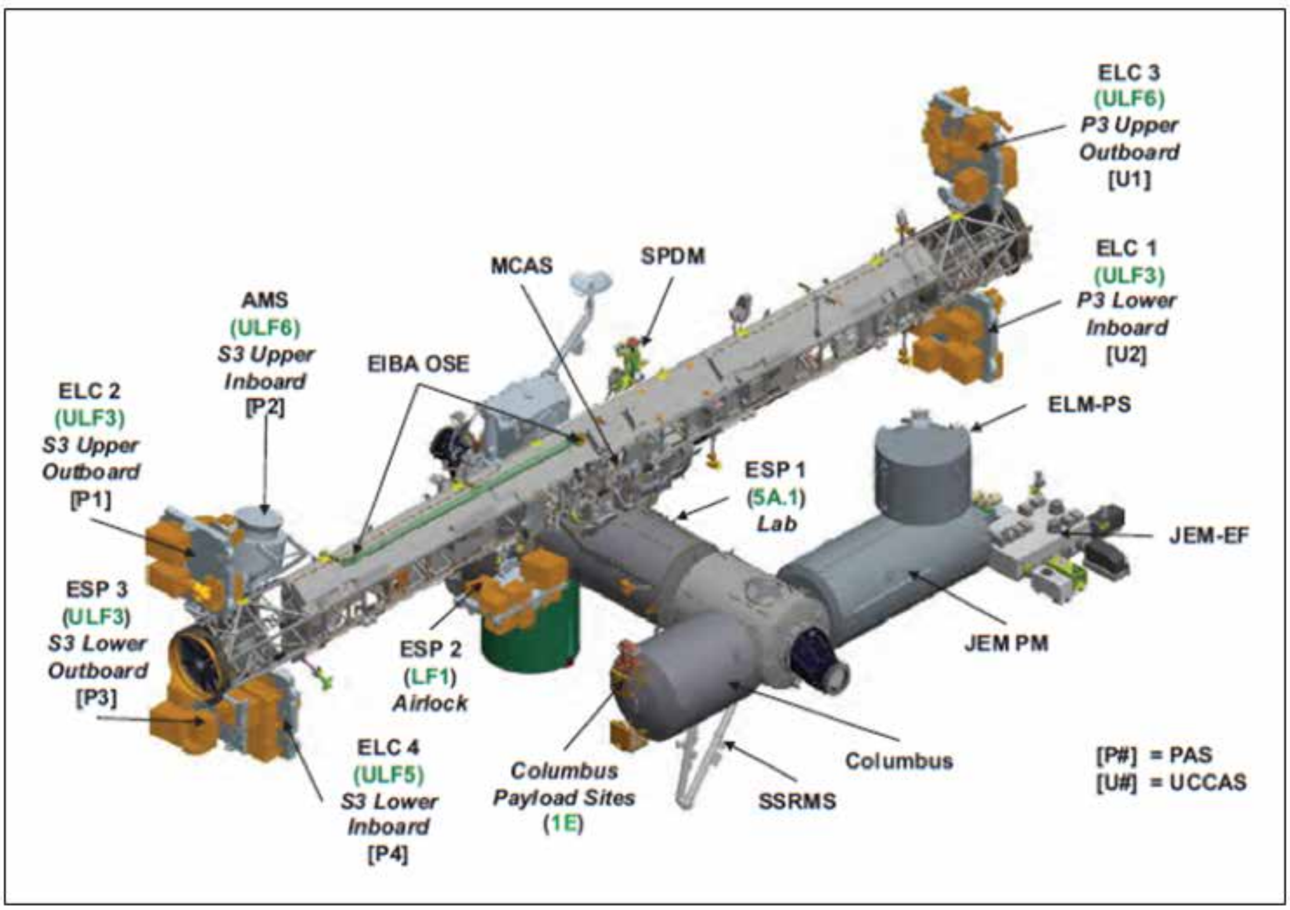
The following figures provide an overview of current ISS configuration and payload platform locations. Tables then summarize the types, locations, and capabilities of the various internal and external platforms for remote sensing from the ISS. This includes the NASA, ESA, and JAXA platforms, and the Teledyne Brown Engineering and NanoRacks commercial platforms, but does not include any from ROSCOSMOS. Significant additional information can be found in the recently released NASA's External Payloads Proposer's Guide to the International Space Station: http://espd.gsfc.nasa.gov/isseppg/GSFC_420-01-09_ISS_ExtPL_Proposers_Guide_Ch01.pdf.



ISS standard external and internal payload platforms for remote sensing (image: adapted from NASA).



Expanded view of ISS configuration as of summer 2015 (image: NASA).



ISS external attachment sites (image: NASA).

MOUNTING POINTS	STATION	U.S. SHARED	COMMERCIAL
Internal			
WORF	3	3	
External			
ELCs	8	8	
Columbus EPFs	4	2	
JEM-EF	12	5	
CAS	6	6	
Commercial			
Muses	4		4
NREP	5		5

INTERNAL PLATFORM	CAPACITY	POWER	THERMAL	DATA
Windows Observational Research Facility (WORF) NASA 3 sites total, all nadir 2 sites optimal configuration	0.8 cu. meter	28 VDC	Controlled “shirtsleeve”	Low: 1 Mbps (1553) Wireless: 100 Mbps

EXTERNAL PLATFORMS	CAPACITY	POWER	THERMAL	DATA
Express Logistics Carrier (ELC) NASA 4 ELCs w/ 2 sites each 2 ELCs on starboard truss 3 (S3) 2 ELCs on port truss 3 (P3) 8 total sites ELC-1 and ELC-4 are nadir ELC-2 and ELC-3 are zenith	227 kg + adapter 1.2 cu. meter	750 W, 113-126 VDC max 500 W @ 28 VDC/adapter	Active heating Passive cooling	Medium: 6 Mbps (shared) Low: 1 Mbps (1553) Wireless: 100 Mbps
Columbus External Payload Facility (Columbus EPF) ESA 4 total sites (2 U.S. shared) SDN is nadir SDX and SOX are ram SOZ is zenith	230 kg + CEPA 1.2 cu. meter	1.25 kW @ 120 VDC 2.5 kW max	Passive heating Passive cooling	Medium: 2 Mbps (shared) Low: 1 Mbps (1553) Wireless: 100 Mbps
Japanese Experiment Module External Facility (JEM-EF) JAXA 12 total sites (5 U.S. shared) 1/3/5/7 are ram, zenith, nadir 2/4/6/8/10 are wake, zenith, nadir 9 is port, zenith, nadir 11/12 are zenith	550 kg (standard) 2250 kg (large) 1.5 cu. meter	3-6 kW, 113-126 VDC max	Passive heating 3-6 kW cooling	High: 43 Mbps Low: 1 Mbps (15t53) Wireless: 100 Mbps
Common Attachment System (CAS) NASA/US Truss 6 total sites 4 sites on starboard truss 3 (S3) 2 sites on port truss 3 (P3) UCCAS-2, PAS-3, PAS-4 are nadir UCCAS-1, PAS-1, PAS-2 are zenith	1360-8618 kg	2 x 3 kW @ 120 VDC	Passive heating Passive cooling	Low: 1 Mbps (1553) Wireless: 100 Mbps

EXTERNAL PLATFORMS	CAPACITY	POWER	THERMAL	DATA
Multi-User System for Earth Sensing (MUSES) Teledyne Brown Engineering (commercial) launch - 2016 ELC-4 Position 2 4 total sites 2 large sites 2 small sites all sites nadir	100 kg (large) 50 kg (small) 92 cm height 46 cm dia (large) 25 cm dia (small)	224 W @ 28 VDC (large) 112 W @ 28 VDC (small)	Passive heating Passive cooling	225 GB/day (shared) Storage: 8 TB Uplink: 1 Mbps (1553) Wireless: 100 Mbps
NanoRacks External Platform (NREP) NanoRacks (commercial) launch – 2015 JEM-EF 4 9 total sites 5 powered 4U payloads; nadir 4 unpowered 3U payloads optional unique payloads	4 kg (4U) 35 kg (unique) 40x10x10 cm (4U) 30x10x10 cm (3U)	50 W @ 28 VDC (powered) 120 VDC (unique max)	Passive heating Passive cooling	Med: 2x10 Mbps (shared) Low: 1 Mbps (1553) Wireless: 100 Mbps

PAYLOAD SELECTION

NASA payload selection for the ISS is predominantly a science-driven process, based on priorities defined by one of the NASA mission directorates, which in turn are guided by the strategies and objectives outlined in NASA's various guiding documents: NASA Strategic Plans, NASA Science Plans, NASA Technology Roadmaps, and the National Research Council (NRC) Decadal Surveys. Within this broader overall NASA structure, remote sensing payloads and remote sensing technologies are addressed primarily by the Science Mission Directorate.

The sources for payloads on the ISS are competed through the standard NASA peer review proposal process, such as the annual Research Opportunities in Space and Earth Sciences (ROSES), the Earth System Science Pathfinder program, and other NASA Research Announcements. Proposals are evaluated according to scientific and technical merit, relevance to NASA's objectives and specific research announcement objectives, realism of proposed research, and cost. International partners and other U.S. organizations, such as the Department of Defense (DoD) Space Test Program (STP), follow similar payload competition and selection procedures, each according to their own programmatic objectives. However, in each case, selected research proposals are not necessarily considered definite payloads, but rather still depend on successful completion of the proposed research, meeting sensor development deadlines, and passing all relevant engineering and safety requirements.

The CASIS remote sensing payload selection process also includes consideration of the scientific value of the proposed sensor concept; however, it also considers the commercial market potential of the sensor technology; the economic and humanitarian value; the market interest in both stand-alone and fused data products from the sensor; and the Science, Technology, Engineering, and Math (STEM) education potential of the technology development process and the resulting data.

PAYLOAD PRIORITIZATION AND LOCATION

From the Plan to Support Operations and Utilization of the International Space Station Beyond FY 2015: "The goal for the prioritization is to preserve the sponsoring organization's internal priorities while balancing the agency level objectives of exploration relevance, utilization impact, international commitments, scientific benefit, interagency commitments and relevance to other government agencies objectives, U.S. commercial commitments, and education and outreach impact. The international partners who have a right to an allocation of the U.S. Operating Segment resources provide their own priorities within their allocation. These priorities are separate from the NASA process, and integration is based on the allocations set in the ISS international agreements."

Payload prioritization and location incorporates a combination of factors, including payload specifications and resource requirements, expected sensor hardware readiness/completion date, funding status, and launch availability. Payload location is assisted by modeling where the sensor would physically fit as a function of mass, volume and power, its data requirements, field-of-view and other viewing constraints, and safety (e.g., active sensors) and environmental concerns (e.g., outgassing). NASA manages this overall planning process using the Multi-Increment Payload Resupply and Outfitting Model (MiPROM), which helps track current and planned utilization of the different external ISS payload mounting points. However, it is noted that the process is very fluid as a result of project delays, changes in funding, launch failures, and changing priorities. Payload prioritization and location is thus an iterative process, which often necessitates significant re-planning to accommodate both unforeseen circumstances and uncertainties in sensor development.

ISS PAYLOADS – PAST, CURRENT AND PLANNED

The following is a list of U.S./NASA ISS missions, inclusive of both Earth observing and atmospheric sensors, in order of launch and implementation. Future dates, mission durations, and payload locations are subject to change. Additional information on current sensors can be found online at the NASA/JSC Earth Science & Remote Sensing Unit website: http://esrs.jsc.nasa.gov/.

- **CEO: Crew Earth Observations, 2000 – ongoing**
  - » **Sensor:** Photographs acquired by ISS crew members | Earth observation
  - » **Location:** Internal | ISS windows, particularly the Cupola
- **EarthKAM: Earth Knowledge Acquired by Middle school students, 2001 – ongoing**
  - » **Sensor:** Photographs acquired for educational outreach program | Earth observation
  - » **Location:** Internal | WORF/U.S. Destiny Lab
- **HICO: Hyperspectral Imager for the Coastal Ocean, 2009 – 2014**
  - » **Sensor:** Hyperspectral imager (380-960 nm) optimized for aquatic targets | Earth observation (coastal)
  - » **Location:** External | HREP on JEM-EF 6
- **RAIDS: Remote Atmospheric and Ionospheric Detection System, 2009 – ongoing**
  - » **Note:** Nominal mission completed; on-orbit duration to be completed in 2016
  - » **Sensors:** Photometers, spectrometers and spectrographs (eight instruments total) | Atmospheric limb
  - » **Location:** External | HREP on JEM-EF 6
- **ISSAC: ISS Agricultural Camera, 2011 – 2013**
  - » **Sensor:** Multispectral imager (Green-Red-Near Infrared [NIR]) | Earth observation (agriculture)
  - » **Location:** Internal | WORF/U.S. Destiny Lab
- **ISERV: ISS SERVIR Environmental Research and Visualization System, 2013 – 2014**
  - » **Note:** Currently stowed in ISS for potential redeployment in late 2015 / early 2016
  - » **Sensor:** Photographs acquired using small telescope | Earth observation
  - » **Location:** Internal | WORF/U.S. Destiny Lab
- **HDEV: High Definition Earth Viewing experiment, 2014 – ongoing**
  - » **Note:** Mission completion expected late 2016 / early 2017
  - » **Sensors:** Four HD video cameras, 1 forward looking, 1 nadir, and 2 backward | Earth observation
  - » **Location:** External | Columbus EPF SDN
- **RapidScat: RapidScat, 2014 – ongoing**
  - » **Note:** Nominal mission duration is 2 years; on-orbit duration to be completed in 2015
  - » **Sensor:** Radar scatterometer at 13.4 GHz (Ku band) | Earth observation (ocean winds)
  - » **Location:** External | Columbus EPF SDX

- **CATS: Cloud-Aerosol Transport System, 2015 – ongoing**
  - **Note:** Nominal mission 6 months – 3 years; mission completion expected by late 2017 / early 2018
  - **Sensor:** Profiling LiDAR at three wavelengths (1064, 532 and 355 nm) | Atmosphere (clouds and aerosols)
  - **Location:** External | JEM-EF 3
- **ISS LIS: ISS Lightning Image Sensor, 2016 launch**
  - **Note:** DoD Space Test Program (STP)-H5; nominal mission 2-4 years; mission completion expected 2018
  - **Sensor:** Optical imager at one narrow wavelength (777 nm) | Atmosphere (lightning)
  - **Location:** External | ELC 1
- **SAGE III: Stratospheric Aerosol and Gas Experiment III, 2016 launch**
  - **Note:** On-orbit duration to be completed in 2020
  - **Sensor:** Profiling grating spectrometer (290-1550 nm) | Atmosphere (ozone and aerosols)
  - **Location:** External | ELC 4
- **ECOSTRESS: ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station, 2017 launch**
  - **Note:** Nominal mission 1 year; on-orbit duration to be completed in 2018
  - **Sensor:** Multispectral thermal radiometer (5 channels from 8-12.5 μm) | Earth observation (vegetation)
  - **Location:** External | JEM-EF 10
- **GEDI: Global Ecosystem Dynamics Investigation Lidar, 2018 launch**
  - **Note:** Mission completion expected by late 2019 / early 2020
  - **Sensor:** Full-waveform LiDAR | Earth observation (forests)
  - **Location:** External | JEM-EF 6
- **OCO-3: Orbiting Carbon Observatory 3, TBD**
  - **Note:** Nominal mission 3 years
  - **Sensors:** Three-channel grating spectrometer (0.76, 1.61 and 2.06 μm) | Atmosphere (carbon dioxide)
  - **Location:** External | JEM-EF TBD

The following is a list of JAXA, German Aerospace Center (DLR) and ESA ISS Earth observing and atmospheric missions in order of launch and implementation. Future dates, durations, and payload locations are subject to change.

- **SMILES (JAXA): Superconducting Submillimeter-Wave Limb-Emission Sounder, 2009 – 2010**
  - **Sensor:** Submillimeter-wave superconducting receiver | Atmosphere (trace gases)
  - **Location:** External | JEM-EF 5
- **MCE (JAXA): Multi-mission Consolidated Equipment, 2012 – 2015**
  - **Platform:** Hosts up to 5 small mission payloads | Earth observation/Atmosphere
  - **Location:** External | JEM-EF 8
- **IMAP (JAXA): Ionosphere, Mesosphere, upper Atmosphere, and Plasmasphere mapping, 2012 – 2015**
  - **Sensor:** Visible and Infrared Spectral Imager (VISI) and Extreme Ultra Violet Imager (EUVI) | Atmosphere
  - **Location:** External | MCE on JEM-EF 8
- **GLIMS (JAXA): Global Lightning and Sprite Measurement Mission, 2012 – 2015**
  - **Sensor:** CMOS cameras, photometers, VLF receiver and VHF interferometer | Atmosphere (lightning)
  - **Location:** External | MCE on JEM-EF 8

- **COTS HDTV-EF (JAXA): Consumer off-the-shelf high-definition television camera under exposed environment, 2012 – 2015**
  - **Sensor:** High-definition video | Earth observation
  - **Location:** External | MCE on JEM-EF 8
- **DESIS-30 (DLR & Teledyne Brown): DLR Earth Sensing Imaging Spectrometer, 2016 launch**
  - **Note:** Nominal mission 5 years; mission completion TBD
  - **Sensor:** Hyperspectral imager (400-1000 nm) | Earth observation
  - **Location:** External | MUSES on ELC 4
- **ASIM (ESA): Atmosphere-Space Interactions Monitor, 2017 launch**
  - **Note:** Mission duration expected through at least 2020; mission completion TBD
  - **Sensors:** Modular X- and gamma-ray sensor, 2 cameras, 3 photometers| Atmosphere (lightning)
  - **Location:** External | Columbus EPF SDX
- **GEROS (ESA): GNSS Reflectometry, radio Occultation and Scatterometry, 2019 launch**
  - **Note:** Mission duration expected through at least 2020; mission completion TBD
  - **Sensor:** GNSS reflectometry receiver | Earth observation (sea surface height and roughness)
  - **Location:** External | Columbus EPF SOX

The following is a list of commercial ISS Earth observing missions and sensor platforms in order of launch and implementation. Future dates, durations and payload locations are subject to change.

- **Iris (Urthecast): Ultra high-definition video camera, 2014 – ongoing**
  - **Note:** Mission duration TBD
  - **Sensor:** Ultra high-definition color video | Earth observation
  - **Location:** External | Russian Zvezda module
- **Theia (Urthecast): Medium-resolution multispectral sensor, 2014 – ongoing**
  - **Note:** Mission duration TBD
  - **Sensor:** Multispectral imager (Blue-Green-Red-NIR) | Earth observation
  - **Location:** External | Russian Zvezda module
- **NREP (NanoRacks): NanoRacks External Platform, 2015 – ongoing**
  - **Note:** Mission duration expected through 2024
  - **Platform:** Host up to 5 nadir-viewing 4U interchangeable sensor payloads | Earth observation
  - **Location:** External | JEM-EF 4
- **MUSES (Teledyne Brown): Multi-User System for Earth Sensing, 2016 launch**
  - **Note:** Mission duration expected through 2024
  - **Platform:** Hosts up to 4 nadir-viewing interchangeable sensor payloads | Earth observation
  - **Location:** External | ELC 4
- **DESIS-30 (DLR & Teledyne Brown): DLR Earth Sensing Imaging Spectrometer, 2016 launch**
  - **Note:** Nominal mission 5 years; mission completion TBD
  - **Sensor:** Hyperspectral imager (400-1000 nm) | Earth observation
  - **Location:** External | MUSES on ELC 4
- **PolarISS (Ursa Space Systems): Synthetic Aperture Radar on the ISS, launch TBD**
  - **Note:** Mission duration TBD
  - **Sensors:** Synthetic Aperture Radar | Earth Observation
  - **Location:** External | TBD

ISS INFRASTRUCTURE EXPANSION OPPORTUNITIES

While the ISS has substantial existing infrastructure and mounting locations for Earth observation sensors, including the addition of commercial platforms from NanoRacks and Teledyne Brown Engineering, resources are nonetheless limited. As demand grows for utilization of the ISS for remote sensing, competition for these limited resources will become an increasingly important factor in the payload selection process. The following suggested opportunities and options for expanding ISS remote sensing capabilities would help alleviate, or at least reduce, these limitations.

- **Increase data rate downlink capacity.** This will facilitate a greater numbers of sensors as well as capacity for greater aggregate spatial and temporal coverage of high data volume sensors (e.g., hyperspectral and full-waveform LiDAR).

- **Improve accuracy and frequency of ephemeris data for each mounting point.** Given the inherent flex in the ISS infrastructure, station ephemerides are often not sufficient for sensors with requirements for high pointing accuracy. Improved ephemerides (e.g., using dedicated star trackers or distributed positioning sensors) would significantly increase the pointing accuracy of remote sensing instruments.

- **Increase resources for CubeSat and smallsat deployment.** This will enhance overall remote sensing capabilities, enable additional data fusion opportunities, and facilitate on-demand response to disasters and other humanitarian events.

- **Expand the number of nadir mounting points.** Despite existing ISS payload capabilities, nadir mounting points are expected to soon reach capacity. Increasing the number of nadir viewing mounting options (e.g., expanding existing ELCs, adding new ELCs, or adding a new dedicated remote sensing platform) will facilitate deployment of more Earth observing sensors.

REMOTE SENSING SCIENCE DATA

NASA EARTH OBSERVING MISSIONS

NASA's Earth Observing System Project Science Office (http://eospso.nasa.gov/) provides information and overviews of all past, current, and proposed future NASA Earth observing satellite and ISS missions, including joint missions with other agencies or countries. Overall this includes 42 completed, 24 current, and 26 future missions. NASA also tracks the value and benefits derived from applications using this Earth science data through the Applied Sciences Program (http://appliedsciences.nasa.gov/).

NASA Earth Science Division currently operating satellite missions as of June 22, 2015 (image: NASA).

NASA EOSDIS REMOTE SENSING DATA SOURCES

Within NASA's Earth Science Data Systems Program, the core framework for managing NASA remote sensing data is the Earth Observing System Data and Information System (EOSDIS)[3], which "ingests, processes, archives, and distributes data from a large number of Earth observing satellites."[4] EOSDIS also includes data from airborne missions, field measurements, and other Earth science related programs.

EOSDIS consists of a national network of twelve Distributed Active Archive Centers (DAACs), which are organized according to Earth science discipline. The EOSDIS DAACs "are custodians of EOS mission data and ensure that data will be easily accessible to users. Acting in concert, the DAACs provide reliable, robust services to users whose needs may cross the traditional boundaries of specific science disciplines, while continuing to support the particular needs of users within the discipline communities."[5] The EOSDIS DAACs include:

- **Alaska Satellite Facility DAAC:** located in the Geophysical Institute at the University of Alaska, Fairbanks and contains data on geophysics, polar processes, sea ice, and synthetic aperture radar products.

- **Atmospheric Science Data Center:** located at NASA Langley Research Center in Hampton, Virginia, and contains data on aerosols, clouds, radiation budget, and tropospheric chemistry.

- **Crustal Dynamics Data Information System:** located at NASA Goddard Space Flight Center in Greenbelt, Maryland, and contains data on solid earth and space geodesy.

- **Global Hydrology Resource Center DAAC:** located at the National Space Science and Technology Center at the University of Alabama in Huntsville, Alabama, and contains data on atmospheric convection, hydrologic cycle, lightning, and severe weather interactions.

- **Goddard Earth Sciences Data and Information Services Center:** located at NASA Goddard and contains data on atmospheric composition and dynamics, global modeling, global precipitation, solar irradiance, and water and energy cycle.

[3] *https://earthdata.nasa.gov/about*
[4] *http://science.nasa.gov/earth-science/earth-science-data/*
[5] *https://earthdata.nasa.gov/about/science-system-description/eosdis-components*

- **Land Processes DAAC:** located at the USGS Earth Resources Observation and Science Center in Sioux Falls, South Dakota, and contains data on ecosystem variables, land cover, radiation budget, surface reflectance, radiance and temperature, topography, and vegetation indices.

- **Level 1 and Atmospheric Archive and Distribution System:** located at NASA Goddard and contains data on atmosphere and MODIS radiance.

- **National Snow and Ice Data Center DAAC:** located at the Cooperative Institute for Research in Environmental Sciences at the University of Colorado at Boulder and contains data on cryosphere, frozen ground, glaciers, ice sheets, sea ice, snow, and soil moisture.

- **Oak Ridge National Laboratory DAAC:** located at the Oak Ridge National Laboratory in Oak Ridge, Tennessee, and contains data on biogeochemical dynamics, ecological data, and environmental processes.

- **Ocean Biology DAAC:** located at NASA Goddard and contains data on: ocean biology and sea surface temperature.

- **Physical Oceanography DAAC:** located at NASA Jet Propulsion Laboratory in Pasadena, California, and contains data on gravity, ocean currents and circulation, ocean surface topography, ocean winds, sea surface salinity, and sea surface temperature.

- **Socioeconomic Data and Applications Center):** located at the Center for International Earth Science Information Network at Columbia University's Lamont-Doherty Earth Observatory campus in Palisades, New York, and contains data on environmental sustainability, geospatial data, human interactions, and land use.

The core entry point for accessing EOSDIS data is Earthdata (https://earthdata.nasa.gov/), which provides a consolidated location for searching datasets, news, and articles. Beyond this centralized search tool, access to EOSDIS data is available through a host of different web-based search and discovery options,[6] which are all free to use but require registration to download data resources. Also within this ecosystem are specialized tools addressing center-specific, data-specific, and even mission-specific data needs. Thus, while the centralized suite of EOSDIS tools are extensive and varied, the volume and diversity of Earth observing data within these archives does not lend itself easily to a single integrated tool. As a result, a certain level of familiarity and expertise is usually required to efficiently navigate the petabytes of data that are available. A discussion of the EOSDIS site, along with a link for those interested in Earth science research, is a potentially valuable addition to the ISS U.S. National Laboratory web portal (http://www.spacestationresearch.com/).

EOSDIS DATA ACCESS TOOLS	DESCRIPTION
Land, Atmosphere Near real-time Capability for EOS (LANCE) https://earthdata.nasa.gov/earth-observation-data/near-real-time	Access near real-time products from the MODIS, OMI, AIRS, and MLS instruments in less than 3 hours from observation
Worldview https://worldview.earthdata.nasa.gov/	Interactively browse full-resolution, global, near real-time satellite imagery from 100+ LANCE and other NASA data products.
Global Change Master Directory (GCMD) http://globalchange.nasa.gov/	GMCD is a database of Earth science data and services, which holds more than 25,000 Earth science datasets and services covering all aspects of Earth and environmental sciences.
Reverb – Data and Services Access Client http://reverb.echo.nasa.gov/reverb/	Allows users, including those without specific knowledge of the data, to search science data holdings, retrieve high-level descriptions of datasets and detailed descriptions of the data inventory, browse images, and submit orders via ECHO to the appropriate data providers.

[6]*https://earthdata.nasa.gov/earth-observation-data*

EOSDIS DATA ACCESS TOOLS	DESCRIPTION
EOS ClearingHouse (ECHO) https://earthdata.nasa.gov/about/science-system-description/eosdis-components/eos-clearing-house-echo	ECHO is a metadata catalog of NASA's EOS data and a registry for related data services, which contains more than 3,200 datasets held at 12 EOSDIS DAACs. Users can access the data and services by using general or community-tailored clients that access ECHO using a series of APIs defined using web services.
DAAC-specific search tools https://earthdata.nasa.gov/earth-observation-data/tools	EOSDIS DAACS provide center-unique tools for functions such as searching, subsetting, and downloading data.
Giovanni http://giovanni.gsfc.nasa.gov/giovanni/	Giovanni provides data search and discovery, direct statistical intercomparison, visualization, and data download for NASA Earth remote sensing missions and other environmental datasets.

ISS REMOTE SENSING DATA SOURCES

For access to remote sensing data from ISS missions, the following provides an overview of resource location within the larger EOSDIS ecosystem and other databases.

ISS MISSION	ISS DATA ACCESS TOOLS
CEO | 2000 – ongoing	**ISS Instrument Integration Interface (I4)** http://issearthserv.jsc.nasa.gov/i4.html **Gateway to Astronaut Photography of Earth** http://eol.jsc.nasa.gov/ **Windows on Earth** http://www.windowsonearth.org/
EarthKAM | 2001 – ongoing	**IISS Instrument Integration Interface (I4)** http://issearthserv.jsc.nasa.gov/i4.html **Sally Ride EarthKam** https://www.earthkam.org/ek-images
HICO | 2009 – 2014	**ISS Instrument Integration Interface (I4)** http://issearthserv.jsc.nasa.gov/i4.html **Oregon State University** http://hico.coas.oregonstate.edu/datasearch/data-search-basic.php **NASA Ocean Color** http://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sen=hi
RAIDS | 2009 – ongoing	**Naval Research Laboratory, Space Science Division** http://www.nrl.navy.mil/ssd/branches/7630/raids/data
ISSAC | 2011 – 2013	**University of North Dakota** Jeffrey VanLooy (contact for info): jvanlooy@aero.und.edu
ISERV | 2013 – 2014	**ISS Instrument Integration Interface (I4)** http://issearthserv.jsc.nasa.gov/i4.html **SERVIR Global** https://www.servirglobal.net/#data\&maps
HDEV | 2014 – ongoing	**Gateway to Astronaut Photography of Earth** http://eol.jsc.nasa.gov/HDEV/

ISS MISSION	ISS DATA ACCESS TOOLS
RapidScat | 2014 – ongoing	**ISS Instrument Integration Interface (I4) (RapidScat currently being added)** http://issearthserv.jsc.nasa.gov/i4.html **Physical Oceanography DAAC** http://podaac.jpl.nasa.gov/
CATS | 2015 – ongoing	**Atmospheric Science Data Center** https://eosweb.larc.nasa.gov/

Note: The ISS Instrument Integration Interface (I4), http://issearthserv.jsc.nasa.gov/i4.html, plans to add all ISS USOS data sources as they become available online.

OTHER REMOTE SENSING DATA SOURCES

In addition to the various NASA EOSDIS and ISS data archives and data access tools, there are a number of other significant U.S. and international resources for obtaining Earth observation data. The following provides a summary of some of the more substantial resources, including both satellite and airborne remote sensing data; however, many more exist, particularly in the international remote sensing community.

OTHER DATA ACCESS TOOLS & RESOURCES	DESCRIPTION
USGS EarthExplorer http://earthexplorer.usgs.gov/	Provides online search, display, metadata export, and download for Earth science data from the archives of the U.S. Geological Survey (USGS).
USGS Global Visualization Viewer http://glovis.usgs.gov/	Online search and order tool for selected satellite and aerial data. The viewer allows user-friendly access to browse images from the multiple EROS data holdings.
USGS Lidar for Science and Resource Management http://coastal.er.usgs.gov/lsrm/	Research datasets (specifically LiDAR and multispectral) supporting the creation of new capabilities for the synoptic remote sensing of coastal-marine and terrestrial environments based on aircraft and satellite sensors.
USGS National Map Viewer http://viewer.nationalmap.gov/viewer/	A collaborative effort among the USGS and other federal, state, and local partners to improve and deliver topographic information for the U.S. The geographic information available includes orthoimagery, elevation, geographic names, hydrography, boundaries, transportation, structures, and land cover.
NOAA Office of Satellite and Product Operations http://www.ospo.noaa.gov/Products/index.html	Includes comprehensive NOAA satellite information and derived products, including archived imagery and operational products for clouds, fire, smoke, weather, precipitation, winds, snow and ice, vegetation, coral bleaching, volcanic ash, and ocean conditions.
NOAA Digital Coast http://coast.noaa.gov/digitalcoast/	Developed to meet the unique needs of the coastal management community. The website provides not only coastal data, but also the tools, training, and information needed to make these data truly useful. Datasets range from economic data to satellite imagery.
NOAA Climate Data Record Program http://www.ncdc.noaa.gov/cdr	Created for preserving climate records from satellite data with time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change.
NASA-JPL AVIRIS http://aviris.jpl.nasa.gov/	Provides access to archived airborne hyperspectral imagery from the Airborne Visible / Infrared Imaging Spectrometer (AVIRIS), a unique cutting-edge research instrument with data from 1992-present.
NASA-JPL MASTER http://masterweb.jpl.nasa.gov/	Provides access to archived data from the MODIS/ASTER (MASTER) airborne simulator, which includes spectral band positions that simulate both the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), which is onboard NASA's Terra satellite, and the Moderate Resolution Imaging Spectroradiometer (MODIS), which is onboard NASA's Terra and Aqua satellites.

OTHER DATA ACCESS TOOLS & RESOURCES	DESCRIPTION
Global Land Cover Facility (GLCF) http://glcf.umd.edu/	Provides Earth science data and products to help everyone to better understand global environmental systems. In particular, the GLCF develops and distributes remotely sensed satellite data and products that explain land cover from the local to global scales.
National Ecological Observatory Network (NEON) http://www.neoninc.org/data-resources/get-data	Airborne remote sensing data (hyperspectral and LiDAR) at specific field sites designed to achieve sub-meter to meter scale ground resolution, bridging scales from organisms and individual stands of vegetation to satellite-based remote sensing.
OpenTopography http://www.opentopography.org/	Facilitates online access to high-resolution (meter to sub-meter scale), Earth science-oriented topography data acquired with LiDAR and other technologies.
Global Earth Observation System of Systems (GEOSS) http://www.geoportal.org/	GEO is a voluntary partnership of governments and organizations that includes 96 nations and the European Commission, and 87 Participating Organizations composed of international bodies with a mandate in Earth observations. Together, the GEO community is creating a Global Earth Observation System of Systems (GEOSS) that will link Earth observation resources world-wide across multiple Societal Benefit Areas.
Committee on Earth Observation Satellites (CEOS) http://ceos.org/data-tools/	CEOS was set up under the aegis of the G7 Economic Summit of Industrial Nations Working Group on Growth, Technology, and Employment. Its core function is to coordinate and harmonize Earth observations to make it easier for the user community to access and use data.
AusCover (Australia) http://www.auscover.org.au/	Provides a data delivery service for provision of Australian biophysical remote sensing data time-series, continental-scale map products, and selected high-resolution datasets over TERN sites.
ESA Earth Online https://earth.esa.int/web/guest/home	Provides access points to data from the full collection of ESA Earth Observing Missions, Third Party Missions, ESA Campaigns, and Copernicus Space Component data.
CEOS Earth Observation Handbook http://www.eohandbook.com/	Presents the main capabilities of satellite Earth observation, applications, and a systematic overview of present and planned Committee on Earth Observing Satellites (CEOS) agency Earth observation satellite missions and their instruments.
WMO Observing Systems Capability Analysis and Review Tool http://www.wmo-sat.info/oscar/spacecapabilities	Contains details of environmental satellite missions, instruments and other related information. Also provides expert assessments on the relevance of instruments for fulfilling some World Meteorological Organization (WMO) pre-defined capabilities and the measurement of particular physical variables.

TOP NASA SCIENCE MISSIONS FOR COMMERCIAL APPLICATIONS

As described above, NASA operates a multitude of space-based Earth observing missions (42 completed, 24 current, and 26 future), and numerous airborne and field campaigns, and distributes thousands of data products through DAACs and web portals. Because NASA embraces an open data policy, these products are freely accessible to the user community and general public. As such, keeping in mind that NASA is science-driven by nature, there is opportunity for leveraging this wealth of NASA data in commercial applications. Here we identify the most relevant Earth observation missions with commercial potential and provide information on the primary resources for accessing data from these missions.

Looking first at currently active missions, there are two key missions with potential utility for commercial application: Landsat 8 and EO-1. Of these, Landsat 8 is the most significant given the longevity of the overall Landsat mission, which dates back more than 40 years, its widespread acceptance within the remote sensing community, and the breadth of applications that have been derived using Landsat imagery. We selected the EO-1 mission for a different reason; it hosts the Hyperion instrument, which is one of the few space-borne hyperspectral imagers, thus providing unique capabilities for developing and testing new analysis techniques in anticipation of future hyperspectral imaging missions. Other notable hyperspectral imagers include HICO and HyspIRI (discussed below under completed and future missions) and DESIS-30, which will soon be deployed on the ISS as a commercial partnership between DLR and Teledyne Brown Engineering. Both Landsat 8 and EO-1 focus predominantly on land and coastal areas, and both acquire imagery at 30 m spatial resolution, which is sufficient scale for a number of commercial applications, particularly those interested in regional or other large-scale assessments. Note that this is nonetheless coarser than the <5 m resolution offered on most commercial instruments and now demanded by many applications.

- **Landsat 8: 2013 – ongoing (nominal mission to 2018)**
  - **Instruments:** OLI (8-band + panchromatic multispectral imager) | TIRS (2-band thermal infrared imager)
  - **Spatial Resolution:** OLI (30 m; panchromatic 15 m) | TIRS (100 m resampled to 30 m)
  - **Advantage:** Global land and coastal acquisitions; 40+ year archive of historic Landsat imagery
  - **Data access:** http://earthexplorer.usgs.gov/
  - **Data access:** http://glovis.usgs.gov/
- **EO-1: 2000 – ongoing (nominal mission was only to 2001)**
  - **Instruments:** Hyperion (220-band hyperspectral imager; 400-2500 nm) | ALI (9-band + panchromatic multispectral imager)
  - **Spatial Resolution:** Hyperion (30 m) | ALI (30 m; panchromatic 10 m)
  - **Advantage:** Hyperspectral imager is relatively unique asset for testing analysis techniques
  - **Data access:** http://earthexplorer.usgs.gov/
  - **Data access:** http://glovis.usgs.gov/

The majority of other current NASA missions focus largely on coarse resolution (>250 m spatial scales) global monitoring satellites that address atmospheric, climate, weather, hydrology, and oceanography applications. Although these data are scientifically valuable across a variety of disciplines, the most apparent commercial value is found in companies that leverage such data (e.g., GOES and NOAA) to provide commercial weather forecasting services. With that in mind, there are also upcoming efforts to further extend weather forecasting to include use of private satellite constellations (e.g., GeoOptics, PlanetiQ, Spire, and Tempus Global Data). Although these latest satellite efforts have not yet been fully realized, this is an area of commercial opportunity to watch in the future.

Outside of the specific missions themselves, there is also commercial value to the various calibration/validation (cal/val) measurement sites NASA and other organizations maintain. It's not the data itself, but rather the use of data to calibrate and validate the accuracy of commercial satellite remote sensing instrument measurements that has value. In most cases, the instrumentation, measurements, and data management for these cal/val sites are supported by different organizations, which means the data are typically distributed across different websites. For land imaging missions, overviews of the most commonly used cal/val sites are provided on the USGS website, http://calval.cr.usgs.gov/rst-resources/sites_catalog/, and through the CEOS Cal/Val Portal, http://calvalportal.ceos.org/home. For aquatic imaging missions, cal/val site information can be found at: MOBY, https://moby.mlml.calstate.edu/; BOUSSOLE, http://www.obs-vlfr.fr/Boussole/; AAOT, http://www.ismar.cnr.it/infrastructures/piattaforma-acqua-alta; and NASA AERONET-Ocean Color, http://aeronet.gsfc.nasa.gov/new_web/ocean_color.html, among others.

Looking now to past missions, we highlight the entire Landsat campaign (Landsat 1-5 and 7) for its commercial potential, based on its historic record (1972-ongoing), its global coverage and spatial resolution, and its extensive utilization across a diversity of applications. We selected the HICO mission on the ISS based on both its hyperspectral imaging capabilities and its unique capacity for evaluating remote sensing applications in coastal areas. As a useful base layer and input for other applications, we selected the Shuttle Radar Topography Mission (SRTM) as a source of global topography data at 30 m spatial resolution. Although the SRTM topography data are being superseded by the commercial WorldDEM product currently being created by Airbus Defense and Space (using data from the DLR TanDEM-X mission), SRTM remains the only freely available global source of high-resolution topography and thus retains significant value for a diversity of applications.

- **Landsat 1-5 and 7: 1972 – 2003* (Landsat 7 still operating, but with data issues since 2003)**
  - **Missions:** Landsat 1 (1972-1978), Landsat 2 (1975-1982), Landsat 3 (1978-1983), Landsat 4 (1982-1993), Landsat 5 (1984-2012), Landsat 6 (1993; failed to reach orbit), Landsat 7 (1999-2003*)
  - **Instruments**: MSS (4-band multispectral imager; Landsat 1-5) | TM (7-band multispectral imager; Landsat 4-5) | ETM+ (7-band + panchromatic multispectral imager; Landsat 7)
  - **Spatial Resolution:** MSS (60 m) | TM (30 m; thermal band resampled from 120 m to 30 m) | ETM+ (30 m; thermal band resampled from 60 m to 30 m; panchromatic 15 m)
  - **Advantage:** Global land and coastal acquisitions; 40+ year archive of historic Landsat imagery
  - **Data access:** http://earthexplorer.usgs.gov/
  - **Data access:** http://glovis.usgs.gov/

- **HICO: 2009-2014**
  - **Instruments:** HICO (87-band hyperspectral imager; 380-960nm)
  - **Spatial Resolution:** HICO (90 m)
  - **Advantage:** Hyperspectral imager is relatively unique asset for testing analysis techniques
  - **Data access:** http://issearthserv.jsc.nasa.gov/i4.html
  - **Data access:** http://hico.coas.oregonstate.edu/datasearch/data-search-basic.php
  - **Data access:** http://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sen=hi

- **SRTM: 2000 (Space Shuttle Endeavour STS-99)**
  - **Instruments:** SRTM (C-Band SAR)
  - **Spatial Resolution:** SRTM (30 m)
  - **Advantage:** Freely available high-resolution global topography
  - **Data access:** http://earthexplorer.usgs.gov/
  - **Data access:** http://glovis.usgs.gov/

And finally, there are future missions that should be kept under consideration as they develop. These include: ECOSTRESS, a multispectral thermal imager with <100 m spatial resolution to be launched in 2017 and deployed on ISS; GEDI, a full-waveform LiDAR sampling 25 m resolution footprints in parallel tracks separated by 500 m to be launched in 2018 and deployed on ISS; HyspIRI, a hyperspectral imager and multispectral thermal imager with 60 m resolution (launch TBD; free-flyer); NISAR, a L- and S-band SAR with <10 m resolution over land and <50 m resolution over sea ice and coastal ocean (launch 2020; free-flyer); LiDAR Surface Topography (LIST), a future/conceptual LiDAR topography mission with 5 m resolution (launch TBD; free-flyer); and Snow and Cold Land Processes (SCLP),a future/conceptual Ku- and X-band SAR for measuring snow accumulation with 50-100 m resolution (launch TBD; free-flyer). Some of these are short-duration demonstration missions (ECOSTRESS, GEDI), and thus have value as pathfinders for future missions, while others are expected to have a larger mission scope (HyspIRI, NISAR, LIST, SCLP), and thus have greater potential for commercial application.

Beyond these suggestions, there is a vast array of additional data and derived products available from NASA and other organizations that may be valuable to specific applications. So the above should not be considered an exhaustive list, but rather a starting point for realizing the added value that can be obtained from leveraging such publically available free data sets.

SENSOR TECHNOLOGIES

NEAR-TERM OPPORTUNITIES

The core sensor technologies that represent the best near-term opportunities for expanding remote sensing on the ISS are: hyperspectral, thermal, LiDAR and SAR. Not unexpectedly, this recommendation coincides with the report by McKinsey & Company, which identifies the same four sensor technologies. Note also that the research and commercial communities have already begun efforts to address these same near-term technology opportunities. DLR and Teledyne Brown Engineering are deploying the hyperspectral imager DESIS-30 on MUSES in 2016, NASA is deploying the thermal and LiDAR sensors ECOSTRESS and GEDI on the ISS in the 2017 to 2018 timeframe, and Urthecast planned for deploying a SAR instrument on the ISS, but has since migrated the concept to a free-flyer constellation. Together these technologies encompass a diverse range of potential application areas and market opportunities that can contribute substantial commercial, humanitarian, and scientific benefits. Although there can be some overlap amongst the different technologies in terms of application area, each technology has its own specific capabilities and thus its own particular advantages within a given application. In forestry applications, for example, hyperspectral data can provide information on species diversity and relative health, while SAR can provide information on canopy height and density. Different sensors providing complementary information are common throughout the remote sensing domain, which indicating that these sensor technologies also provide benefits in terms of data fusion applications (discussed in more detail below).

Among all these technologies there are options to deploy sensors as airborne (conventional aircraft or unmanned aerial vehicles [UAV]) or space-based systems (ISS or free-flyer satellites). Advantages of airborne deployment include custom flight planning to optimize environmental conditions and target coverage, opportunities for on-demand data acquisition, the ability to modify or update sensor hardware, and the capacity for higher spatial resolution data, with data volume only limited by onboard storage capabilities. Advantages of space-based deployment include the capability for global or globally distributed data acquisition, economy of scale for collection of large data sets, efficiency and relative ease of repeat coverage through time, capacity for opportunistic or on-demand acquisition of global target areas, and the consistency of data characteristics both spatially and temporally. Given these different advantages, there are ultimately different markets and different application opportunities for each option. Although there is overlap between the two, the primary distinction is that airborne is better suited for localized applications with or without specific environmental or time-of-day requirements, and space-based is better suited for large-scale spatial or temporal coverage, remote or difficult to access areas, and global applications. Assuming proposed sensors aren't otherwise limited (e.g., size, power, or data), these considerations can serve as additional criteria when selecting new sensor technologies for the ISS.

Not included in the list of near-term opportunities is multispectral remote sensing, which is one of the most common, and, successful, sensor technologies. It is not that this technology doesn't have value, however. There is a long history of beneficial applications derived from multispectral data, most notably the wealth of scientific, commercial, and humanitarian benefits that have emerged from the Landsat program. Additionally, high resolution multispectral imaging is a mainstay of the commercial satellite industry, including both individual free-flyer satellites (e.g., DigitalGlobe's QuickBird, IKONOS, and WorldView-2 satellites) and the growing prevalence of free-flyer satellite constellations (e.g., Planet Labs, Skybox Imaging, OmniEarth, and BlackSky Global). Thus, multispectral remote sensing has definitive value, but there is already significant innovation and data availability occurring in this technology domain. Hence, it is not included as a near-term opportunity for the ISS.

With that said, sensor selection should be open-minded to all promising and innovative technologies. Even multispectral or video technologies that represent substantial advances in the next generation of sensors should be considered.

The following is a summary of the general characteristics of each of the four sensor technologies defined as near-term opportunities: hyperspectral, thermal, LiDAR, and SAR. Each technology has many nuances, not all of which can be described here, hence there are additional capabilities and applications that extend beyond what is included here.

SENSOR TECHNOLOGY	CHARACTERISTICS AND APPLICATIONS FOR EARTH OBSERVATION
Hyperspectral	**Sensor Characteristics** • Passive remote sensing • Records reflected or emitted energy in several (typically >50) narrow contiguous wavelengths (typically ≤10 nm) across the electromagnetic spectrum • Key advantage: provides spectral signatures for materials identification • Common sensors: 400-1000 nm (VIS-NIR) or 400-2500 nm (VIS-NIR-SWIR) **Sensor Examples** • Satellite/ISS: HYPERION, HICO, HyspIRI, DESIS-30 • Airborne: AVIRIS, AISA, CASI, HYMAP **Example Applications** • Agriculture & Forestry • Minerology/Geology • Oil & Gas • Coastal/Aquatic
Thermal	**Sensor Characteristics** • Passive remote sensing • Records emitted energy in the thermal infrared portion of the electromagnetic spectrum (typically between 3-14 μm) • Key advantage: measures emitted heat • Sensors can be multispectral or hyperspectral **Sensor Examples** • Satellite/ISS: Landsat, ASTER, MODIS, ECOSTRESS/PHyTIR • Airborne: MASTER, HyTES, TASI, G-LiHT **Example Applications** • Agriculture & Forestry • Forest fires • Soil moisture • Volcanology • Sea surface temperature
LiDAR	**Sensor Characteristics** • Active remote sensing • Emits pulses of light using a laser and measures the backscattered or reflected light from these pulses that returns to the sensor • Key advantage: can simultaneously map vegetation canopy and ground surface • Typical laser wavelengths: 1064 nm (topography) and 532 nm (bathymetry) • Sensors measure either discrete or full-waveform returns **Sensor Examples** • Satellite/ISS: LITE, GLAS (on ICESat), GEDI • Airborne: LVIS, OPTECH, RIEGL, EAARL **Example Applications** • Agriculture & Forestry • Topographic & Bathymetric mapping • Flood modeling • Infrastructure management • Urban planning

[7] *Evans, D. L., Apel, J., Arvidson, R., Bindschadler, R., & Carsey, F. (1995). Spaceborne Synthetic Aperture Radar: Current Status and Future Directions. A Report to the Committee on Earth Sciences. JPL, Pasadena CA.*

SENSOR TECHNOLOGY	CHARACTERISTICS AND APPLICATIONS FOR EARTH OBSERVATION
SAR	**Sensor Characteristics** • Active remote sensing • Emits pulses of microwaves and measures the backscattered or reflected energy from these pulses that return to the sensor • Key advantage: can measure through clouds and smoke • Different sensors operate at different bands/frequencies, depending on the intended applications: P-band (0.23-1 GHz, 130-30 cm), L-band (1-2 GHz, 30-15 cm), S-band (2-4 GHz, 15-7.5 cm), C-band (4-8 GHz, 7.5-3.75 cm), X-band (8-12.5 GHz, 3.75-2.40 cm), Ku-band (12.5-18 GHz, 2.40-1.67 cm), K-band (18-26.5 GHz, 1.67-1.13 cm), and Ka-band (26.5-40 GHz, 1.13-0.75 cm) (Evans et al. 1995)[7] • Generally, the smaller the frequency (longer the wavelength) the greater the penetration into vegetation and soil, and the larger the frequency (shorter the wavelength) the smaller the size of surface features that can be distinguished • SAR systems can operate using the same polarization for sending and receiving (single polarization; e.g., HH or VV; H is horizontal and V is vertical polarization) or different polarizations (multi-polarization; e.g., HH-HV-VH-VV), where multi-polarization provides improved classification information **Sensor Examples** • Satellite/ISS: ERS-1/2, TerraSAR-X/TanDEM-X, RADARSAT-1/2 • Airborne: AIRSAR, UAVSAR, E-SAR, F-SAR **Example Applications** • Agriculture & Forestry • Topographic mapping • Land deformation/subsidence • Flood mapping • Oil spills • Sea ice/glacier monitoring • Oceanography (waves)

IDEAL SENSOR SUITE

Selecting an ideal sensor suite depends on the applications you want to address and the questions you are trying to answer. Nonetheless, while acknowledging that a certain level of subjectivity is involved, an initial combination of general sensor specifications is selected here as a means to initiate the conversation and prompt further discussion.

SENSOR TECHNOLOGY	SENSOR SPECIFICATIONS
Hyperspectral	**Specifications** • Spectral range 400-2500 nm • Spectral sampling 400-1000 nm @ ≤5 nm (VNIR; ~120 bands) • Spectral sampling 1000-2400 nm @ ≤10 nm (SWIR; ~140 bands) • Spatial resolution ≤30 m **Example sensors under development** • HyspIRI, EnMAP, DESIS-30
Thermal	**Specifications** • Spectral range 3-14 μm • Multispectral with ≥10 bands • Bandwidth 3-6 μm @ ≤0.2 μm; 6-14 μm @ ≤0.5 μm • Spatial resolution ≤30 m **Example sensor under development** • ECOSTRESS/PHyTIR
LiDAR	**Specifications** • Full-waveform LiDAR • Laser wavelength 1064 nm • Spatial resolution ≤20 m footprint **Example sensor under development** • GEDI
SAR	**Specifications** • Dual-band SAR with X-band and L-band • Dual-polarized X-band (HH-VV or HH-HV or VV-VH) • Quad-polarized L-band (HH-HV-VH-VV) • Spatial resolution X-band ≤1 m (high-resolution); ≤5 m (med-resolution) • Spatial resolution L-band ≤10 m (high-resolution); ≤20 m (med-resolution) **Example sensor under development** • Urthecast SAR-XL, Ursa Space Systems PolarISS

DATA FUSION OPPORTUNITIES

Data fusion in remote sensing encompasses a range of definitions and a diversity of potential applications. Data fusion typically involves different sensor types, but can also involve similar sensor types with different characteristics or constellations of similar sensors. Some examples include: merging of hyperspectral, LiDAR, and thermal data (e.g., NASA's airborne G-LiHT observatory) to assess forest health and productivity; using data from tandem SAR sensors (e.g., TerraSAR-X and TanDEM-X) to generate high accuracy global Digital Elevation Models (DEMs); combining SAR and hyperspectral data to improve change detection in urban areas; employing layers of multispectral data from constellations of sensors (e.g., Planet Labs) to provide daily monitoring of crop health; utilizing aerosol information derived from LiDAR sensors (e.g., CALIPSO or CATS) to improve atmospheric correction of multispectral ocean color data (e.g., MODIS/Aqua); and merging SAR with hyperspectral or multispectral data to inform agricultural irrigation needs.

Data fusion can also occur at different processing levels, such as: integrating raw data sources from different sensors into specific algorithms (e.g., fusing hyperspectral and thermal data into classification analysis); combining individual output products from different sensors into higher level output products (e.g., fusing LiDAR derived canopy height and hyperspectral vegetation classification to derive agricultural yield); and hybrid approaches combining raw data from one sensor with output products from another sensor to generate higher level products (e.g., fusing surface texture derived from LiDAR with hyperspectral data to enhance mineral classifications for geologic mapping).

Another aspect of data fusion, commonly used in the intelligence community, is the concept of tipping and cueing. This is where information derived from one sensor is used to initiate additional, more detailed, information being collected using another sensor. Tipping and cueing is also relevant outside the intelligence community, such as using moderate resolution imagery of crop conditions to inform when high resolution imagery should be used to investigate irrigation shortages or areas of low health and using change detection of moderate or high resolution imagery of utility or railway rights-of-way to indicate when on-site inspections are needed of potential problem areas.

With all this in mind, what makes the ISS particularly unique for data fusion in remote sensing is the ability to co-locate sensors on the same platform at the same time, significantly improving opportunities to develop new data fusion techniques. The MUSES platform is a good example of how this can be achieved on the ISS. Additionally, allowing multiple sensors to concurrently observe the same location on the Earth's surface reduces some of the uncertainties related to varying atmospheric and surface conditions typically associated with asynchronous acquisitions. The ISS also offers unique revisit frequency and acquisition times as compared with traditional polar orbiting sun-synchronous sensors. As such, sensors on the ISS can provide measurements at different times of day and at different viewing and illumination geometries that would otherwise be difficult to obtain. Although applications using this capability are still largely being explored, research shows promise for opportunities such as capturing short-term ephemeral events, using tipping and cueing from the ISS to initiate acquisitions from a free-flying satellite, and utilizing the unique timing and acquisition geometry of the ISS to derive additional information layers.

The ISS thus provides a unique platform for data fusion opportunities, including use as a complementary source of data for fusion with polar orbiting sun-synchronous sensors. Such opportunities extend across many different research disciplines and commercial applications, and the examples mentioned here are but a subset of what is possible. Furthermore, data fusion remains an active area for research and development in remote sensing, and the ISS is well positioned as a technology testbed to contribute to this domain.

INNOVATIVE PAYLOADS

Given the unique advantages of the ISS as a remote sensing platform, particularly its infrastructure resources and ability to co-mount various sensors and supporting technologies on the same platform, there is ample opportunity for deploying innovative payloads on the ISS. Below are examples of some promising innovative payloads; however, it is expected that the community itself will dictate new directions in innovation, and that new ideas will surface as the ISS continues to expand its role as an Earth observation platform.

- **Combinations or sets of complementary sensors for data fusion.** The co-location of different sensor technologies on the ISS has largely been opportunistic rather than planned, and it would be beneficial to strategically coordinate deployment of multiple sensor technologies that explicitly include data fusion in their mission objectives.

- **Technologies for sensor calibration and cross-calibration.** Deriving accurate products from remote sensing data requires establishing and maintaining accurate sensor characterization and calibration, and in many cases, data fusion similarly requires accurate sensor cross-calibration. Although these processes are commonly performed independently for different missions, or by using application-specific validation datasets in the case of cross-calibration, developing shared instrumentation to calibrate multiple sensors (e.g., on-board calibration lamps or measurements of the lunar surface shared via fiber optics, moveable calibration panels, or even a new rotating external payload platform allowing lunar calibration) would contribute both efficiency and uniformity to the calibration process.

- **Missions utilizing sensor-to-sensor communication.** Remote sensing payloads typically operate as independent systems, but the ability to co-locate multiple sensors on the ISS gives an opportunity for innovative data fusion applications where sensor-to-sensor communication (likely through the wireless network) will enable coordinated data acquisition, automated tipping and cueing, and optimized acquisition scheduling to either avoid or target specific environment conditions (e.g., clouds and smoke), among others.

- **Missions that advance the next generation of sensor technologies.** As with the entire tech industry, advances in remote sensing technology are continually being made in hardware, software, size, weight, performance, efficiency, and cost. Benefits for the entire remote sensing industry can be gained by continuing to utilize the ISS as a demonstration platform for these technological advances.

SUPPORTING TECHNOLOGIES

In addition to the sensor technologies themselves, there are also a number of supporting technologies that improve operating efficiency, increase data capacity, and expand remote sensing application opportunities. As previously mentioned a few of these technologies, such as increasing data downlink capacity, improving the accuracy and frequency of ephemeris data, utilizing sensor-to-sensor communication via the wireless network, and expanding capabilities for CubeSat and smallsat deployments. The following are additional supporting technologies to take into consideration:

- **Onboard data processing.** Investments in innovative technologies for onboard computing and image processing, such as single-board computers, field-programmable gate arrays (FPGAs), and graphics processor units (GPUs), provide capabilities for data compression, quality control, and real-time product generation.

- **Ground-based data processing.** Equally important as acquiring data are technologies for analyzing this data, deriving value-added products, and delivering this information to the customer. Such technologies include cloud computing, high-performance computing, data formats and interoperability, data fusion, and turnkey data processing systems.

- **Data analytics.** Building further on and adding another level of analysis to data processing is the need for innovative data analytics solutions (e.g., software, algorithms, and computing platforms), including both commercial and open-source data processing solutions, to extract social and economic relationships and behaviors as a function of the geospatial information derived from remote sensing data.

- **Citizen science.** The ISS and free-flyers are acquiring an expansive and growing volume of remote sensing data, and the corresponding volume of value-added data products continues to grow as well. In some cases, citizen science (aka, crowd sourcing) can be utilized to contribute to the process of validating these output products at large-scales, which otherwise can be challenging or impractical to accomplish.

- **Additive 3D printing.** The ISS has the unique ability to deploy small satellites on-demand, or in the case of additive 3D printing, assemble and deploy small CubeSats on-demand, providing opportunities for responding to environmental disasters and other humanitarian needs.

PROBLEMATIC TECHNOLOGIES

This analysis has not yet identified any problematic technologies; however, it is expected that certain sensor technologies will be limited by downlink capacity (e.g., high data volume hyperspectral and full-waveform LiDAR) and power requirements (e.g., certain LiDAR and SAR). Additionally, safety concerns typically dictate that active sensors (e.g., LiDAR and SAR) not transmit during vehicle docking and undocking procedures or extra-vehicular activities. These technologies are not necessarily problematic, but may experience periods of limited operation, which should be taken into account when considering data acquisition requirements. Another aspect of potential data acquisition limitations is that the ISS does not accommodate observation of the polar regions, and thus isn't appropriate for missions intended to be global mappers. Nonetheless, the ISS covers approximately 90% of Earth's populated area every 90 minutes, so significant opportunity still exists for large-scale mapping missions.

POINTS OF CONTACT

SYNOPSIS

The following is a list of contacts relevant to the CASIS Good Earth campaign, including individuals at NASA and companies involved in commercial Earth observation, sensor development, data processing, and other supporting remote-sensing technologies. Also included are contacts listed in the McKinsey & Company report and those already identified by CASIS as significant aerospace industry partners. With few exceptions, the majority of companies listed here are U.S. companies; non-U.S. companies were generally excluded. Additionally, analysis focused on identifying companies providing complete remote sensing systems; not listed, again with a few exceptions, are the numerous individual component manufacturers that contribute to sensor and spacecraft development.

Presented below is a summary of contacts arranged by category, followed by tables with detailed information on each of the listed contacts. Identified throughout (*) are individuals or specifically contacted regarding campaign Good Earth during the process of conducting this Gap Analysis.

NASA

ISS Platform

***Sharon Conover (NASA-JSC),** Manager, NASA Research Office

Marybeth Edeen (NASA-JSC), Manager, ISS Research Integration Office

Carlos Fontanot (NASA-JSC), Imagery Manager, ISS

Rod Jones (NASA-JSC), Manager, ISS Avionics and Software Office

George Nelson (NASA-JSC), Manager, ISS Technology Demonstration Office

Mike Read (NASA-JSC), Manager, ISS National Laboratory

***Julie Robinson (NASA-JSC), Chief** Scientist, ISS

Sam Scimemi (NASA-HQ), Director, ISS

***William Stefanov (NASA-JSC),** Associate ISS Program Scientist for Earth Observation

Earth Observation Data

Lawrence Friedl (NASA-HQ), Director, Applied Sciences Program

Gary Jedlovec (NASA-MSFC), Atmospheric Scientist, Global Hydrology and Climate Center

Matt McGill (NASA-GSFC), Earth Science Division Chief Technologist

***Kevin Murphy (NASA-HQ),** Earth Science Data Systems Program Executive, Science Mission Directorate

***Steven Neeck (NASA-HQ),** Deputy Associate Director, Science Mission Directorate

***William Stefanov (NASA-JSC),** Associate ISS Program Scientist for Earth Observation

Commercial Earth Observation

ISS Platform

NanoRacks, NanoRacks CubeSat Deployer (NRCSD), NanoRacks External Platform (NREP); launched 2015

***Teledyne Brown Engineering,** Multi-User System for Earth Sensing (MUSES); scheduled launch 2016

***Teledyne Brown Engineering/DLR,** DESIS-30 hyperspectral imager; scheduled launch 2016

***Urthecast,** Multispectral imager (Theia) and ultra-HD video (Iris); currently operational

***Ursa Space Systems,** forthcoming SAR (PolarISS); launch TBD

Satellite

Aquila Space, forthcoming/proposed multispectral satellite constellation; initial deployment 2016

BlackSky Global, forthcoming/proposed multispectral satellite/video constellation; initial deployment 2016

DigitalGlobe, established/industry-leading multispectral satellite constellation; currently operational

GeoOptics, forthcoming/proposed weather satellite constellation; initial deployment 2016

HySpecIQ, forthcoming/proposed hyperspectral satellite constellation; initial deployment 2018

NorStar Space Data, forthcoming/proposed hyperspectral satellite constellation; deployment TBD

OmniEarth, forthcoming/proposed multispectral satellite constellation; scheduled deployment 2018

PlanetiQ, forthcoming/proposed weather satellite constellation; initial deployment 2017

Planet Labs, recent/expanding multispectral satellite constellation; currently operational

Skybox Imaging, recent/expanding multispectral/video satellite constellation; 2 prototypes operational

Spire Global, forthcoming/proposed weather satellite constellation; initial 4 satellite deployed 2015

Tempus Global Data, forthcoming/proposed weather satellite constellation; initial deployment 2017

***Urthecast,** forthcoming/proposed SAR/multispectral/video satellite constellation; initial deployment 2017

***Ursa Space Systems,** forthcoming/proposed SAR satellite constellation; deployment TBD

Sensor Technologies

Hyperspectral

BaySpec, airborne hyperspectral imaging systems

Brandywine Photonics, hyperspectral sensors for airborne and space applications

Headwall Photonics, hyperspectral sensors for airborne and space applications

Johns Hopkins University Applied Physics Laboratory, hyperspectral space applications

NASA Jet Propulsion Laboratory, hyperspectral, thermal, LiDAR, and SAR space and airborne applications

NovaSol, hyperspectral sensors, turnkey imaging, and navigation solutions

Resonon, airborne hyperspectral imaging systems

Thermal

FLIR, specializes in thermal imaging cameras

NASA Jet Propulsion Laboratory, hyperspectral, thermal, LiDAR, and SAR space and airborne applications

Sierra-Olympic Technologies, airborne and ground-based thermal imaging systems

LiDAR

Astra, multiple technologies, including CubeSats and LiDAR

Fibertek, solid-state sensors and electro-optical sensors, including LiDAR

NASA Jet Propulsion Laboratory, hyperspectral, thermal, LiDAR, and SAR space and airborne applications

RIEGL USA, unmanned, airborne, mobile, and terrestrial LiDAR

Sigma Space, high-efficiency single-photon LiDAR systems

Teledyne Optech, airborne LiDAR imaging systems, including bathymetric LiDAR

Velodyne LiDAR, airborne/UAV, automotive, and other vehicle-based LiDAR

SAR

Artemis, airborne and space SAR platforms

Imsar, SAR airborne imaging and real-time processing

NASA Jet Propulsion Laboratory, hyperspectral, thermal, LiDAR, and SAR space and airborne applications

Nuvotronics, SAR and radar components, instruments, and sensor solutions

Sandia National Labs, more than 30 years of experience in SAR development

SRC, SAR and radar airborne applications

Supporting Technologies

Components/Sensors

Alliance Spacesystems, payload, bus, satellite, and launch vehicle structures; solar power solutions

Dartmouth College, innovative Quanta Image Sensors, under development

e2v, CMOS, CCD, and EMCCD imaging sensors, arrays, and cameras

HNu Photonics, optics, telescopes, and spectral calibration

Analytics/Software

Astro Digital, data access and image processing

DigitalGlobe, data access, big data analytics and image processing

FLIR, RapidRecap video technology identifies and embeds unique events in a single condensed video

***HySpeed Computing,** software and application development, including cloud computing

OmniEarth, image processing, data fusion, big data, and predictive analytics

Orbital Insight, market intelligence through image analysis

Planet Labs, data access, big data analytics, and image processing

RS Metrics, investment and business intelligence through image analysis

Skybox Imaging, data access, big data analytics, and image processing

Spaceknow, data access, analytics, and business intelligence

***The HDF Group,** standardized data management and format

Data Processing Hardware

***Business Integra,** geospatial data processing hardware and services

***ViON,** turnkey data storage and data processing systems

Additional Contacts

McKinsey & Company Report

Google Maps Business Development

Norway's International Climate and Forest Initiative

Rensselaer Polytechnic Institute

University of Maryland, Department of Geographical Sciences

Woods Hole Research Center

CASIS Aerospace Contacts

Aerospace Corporation

ATK (Orbital)

Ball Aerospace

Blue Origin

Boeing Satellite Systems

Gencorp (Aerojet/Rocketdyne)

Harris

L-3 Communication

Lockheed Martin Commercial Space

Lockheed Martin Space Systems

Lockheed Martin Space Technology Advanced Research and Development Laboratories (STAR Labs)

Moog

Northrop Grumman

Raytheon

Riverside Research (Applied Research Solutions)

Rocket Lab

Surrey Satellite Technology US LLC

Teledyne Brown Engineering

USAF/SMC - NRO

NASA | ISS PLATFORM

CONTACTS: NASA | ISS PLATFORM	COMMENTS
***Sharon Conover (NASA-JSC)** Manager, NASA Research Office ISS Research Integration Office sharon.c.conover@nasa.gov 281.244.8158	Payload/research integration **Notes:** Contacted in-person at ISS R&D and email
Marybeth Edeen (NASA-JSC) Manager, ISS Research Integration Office marybeth.a.edeen@nasa.gov 281.483.9122	Management of payload integration and scheduling for ISS
Carlos Fontanot (NASA-JSC) Imagery Manager, ISS carlos.fontanot-1@nasa.gov 281.483.2398	Image acquisition, distribution and archiving; ISS data/information transfer
Rod Jones (NASA-JSC) Manager, ISS Avionics and Software Office william.r.jones@nasa.gov 281.244.7941	Avionics and software services and maintenance
George Nelson (NASA-JSC) Manager, ISS Technology Demonstration Office george.nelson-1@nasa.gov 281.244.8514	NASA-funded technology development and demonstration investigations and DoD investigations
Mike Read (NASA-JSC) Manager, ISS National Laboratory michael.e.read@nasa.gov 281.244.7656	Investigations from other government agencies, non-profit and commercial organizations
***Julie Robinson (NASA-JSC)** Chief Scientist, ISS julie.a.robinson@nasa.gov 281.483.5582	Science lead for all ISS research **Notes:** Contacted in-person at ISS R&D
Sam Scimemi (NASA-HQ) Director, ISS sam.scimemi@nasa.gov 202.358.0865	Overall ISS director
***William Stefanov (NASA-JSC)** Associate ISS Program Scientist for Earth Observation william.l.stefanov@nasa.gov 281.483.5139	ISS internal and external payloads, science application areas, and ISS data access **Notes:** Contacted in-person at ISS R&D and multiple telecons

NASA | EARTH OBSERVATION DATA

CONTACTS: NASA | EARTH OBSERVATION DATA	COMMENTS
Lawrence Friedl (NASA-HQ) Director, Applied Sciences Program lfriedl@nasa.gov 202.358.1599	NASA Earth observation data access; facilitation of data use by businesses, non-profits, governments and other organizations in applied science applications
Gary Jedlovec (NASA-MSFC) Atmospheric Scientist, Global Hydrology and Climate Center gary. jedlovec@nasa.gov 256.961.7966	Data fusion and algorithm development for regional climate studies and weather forecasting applications
Matt McGill (NASA-GSFC) Earth Science Division Chief Technologist Physical Scientist, Mesoscale Atmospheric Processes Laboratory matthew.j.mcgill@nasa.gov 301.614.6281	Data fusion and remote sensing instrument development; CATS Principal Investigator

CONTACTS: NASA | EARTH OBSERVATION DATA	COMMENTS
***Kevin Murphy (NASA-HQ)** Earth Science Data Systems Program Executive Science Mission Directorate kevin.j.murphy@nasa.gov 202.358.3042	Overall NASA Earth science data access, visualization and policies **Notes:** Contacted via CASIS telecon with Dan Blaettler
***Steven Neeck (NASA-HQ)** Deputy Associate Director Science Mission Directorate steven.neeck@nasa.gov 202.358.0832	Overall NASA Earth science data access, visualization and policies **Notes:** Contacted via CASIS telecon with Dan Blaettler
***William Stefanov (NASA-JSC)** Associate ISS Program Scientist for Earth Observation william.l.stefanov@nasa.gov 281.483.5139	ISS internal and external payloads, science application areas, and ISS data access. **Notes:** Contacted in-person at ISS R&D and multiple telecons

COMMERCIAL EARTH OBSERVATION | ISS PLATFORM

CONTACTS: COMMERCIAL EARTH OBSERVATION | ISS PLATFORM	COMMENTS
NanoRacks http://nanoracks.com/ 555 Forge River Road, Suite 120 Webster, TX 77598 Jeffrey Manber, Managing Director	Earth observation platform, sensor integration and system operation; NREP platform on ISS; launched 2015
Teledyne Brown Engineering https://www.tbe.com/ 300 Sparkman Drive, Cummings Research Park PO Box 070007, Huntsville, AL 35805 ***Mark S. Whorton, Chief Technology Officer** mark.whorton@teledyne.com 256.726.1924 (office) 256.541.1980 (mobile) ***Reggie Spivey, Manager,** ISS Commercial Payload Integration reggie.spivey@teledyne.com 256.726.1251 (office) 256.541.4178 (mobile)	Earth observation platform, sensor integration and system operation; MUSES platform on ISS; scheduled launch 2016 Hyperspectral imager, in partnership with DLR; DESIS-30 will be first sensor installed on MUSES; scheduled launch 2016 **Notes:** Contacted both Whorton and Spivey in-person at ISS R&D
Urthecast https://www.urthecast.com/ 111 West Port Plaza, Suite 300 St. Louis, MO 63146 ***Phil Downen, VP Government Programs** pdownen@urthecast.com 314.227.0370 (office) 636.426.0288 (mobile) ***Dave Welch, Software Engineer** dwelch@urthecast.com 314.288.0532 (direct) 314.585.7422 (mobile) ***Hojin Kim, Remote Sensing Scientist** hjkim@urthecast.com 314.403.7678 (direct) 215.203.2019 (mobile)	Earth observation data as a service, with a multispectral sensor (Theia) and ultra-HD video (Iris) already on ISS (currently operational); upcoming plans for a constellation of 16 satellites (8 dual-mode optical satellites, including video and multispectral, and 8 SAR satellites); initial satellite deployment scheduled 2017 **Notes:** Contacted Downen in-person at ISS R&D and Welch and Kim in-person at ENVI Analytics Symposium
Ursa Space Systems http://www.ursaspace.com/ 314 E State St, Suite 200 Ithaca, NY 14850 ***Julie Baker** Co-Founder julie@ursaspace.com 607.279.1498	**SAR;** forthcoming SAR sensor on ISS (PolarISS) as well as proposed SAR satellite constellation utilizing unique low-cost SAR sensor system; deployments TBD **Notes:** Contacted Baker in-person at ENVI Analytics Symposium; company is recently funded by CASIS

COMMERCIAL EARTH OBSERVATION | SATELLITE

CONTACTS: COMMERCIAL EARTH OBSERVATION | SATELLITE	COMMENTS
Aquila Space (partnered with Astro Digital) http://www.aquilaspace.com/ NASA Ames Research Park Building 503 340 Cody Road Moffett Field, CA 94035 info@aquilaspace.com	**Multispectral;** forthcoming 30 satellite constellation; 20 satellites with 5-band multispectral + panchromatic and 10 satellites with 3-band multispectral; initial deployment scheduled for 2016 Partnered with Astro Digital, who provides an online platform for data access, analysis and analytics Multispectral satellites; also manufactures and sells complete satellites, satellite platforms, and sub-systems and components
BlackSky Global http://www.blacksky.com/ 3415 S. 116th Street, Suite 123 Tukwila, WA 98168	**Multispectral and video;** forthcoming 60 satellite constellation providing satellite imaging as a service, with 3-band (rgb) multispectral and video; constellation will utilize combination of 52 degrees inclined and sun synchronous orbits; initial deployment of 6 satellites scheduled 2016
DigitalGlobe https://www.digitalglobe.com/ 1300 W. 120th Ave (headquarters) Westminster, CO 80234 800.655.7929 303.684.4000	**Multispectral;** leading global provider of commercial high resolution multispectral Earth imagery products and services; currently includes 5 active satellites; WorldView-3, the most recent satellite, measures 28 bands + panchromatic Also provides Geospatial Big Data Platform for online data access, analysis and analytics; includes access to DigitalGlobe's 15 years of satellite imagery totaling around 70 petabytes of data
GeoOptics http://geooptics.com/ 201 N. Orange Grove Blvd., Suite 503 Pasadena, CA 91103 info@geooptics.com 713.296.0293	**Weather;** forthcoming 24 weather satellite constellation, with GPS-radio occultation sensors; initial deployment of 6 satellites scheduled for 2016, with expansion to 12 satellites by 2017 and 24 satellites by 2018
HySpecIQ http://www.hyspeciq.com/ 2020 Pennsylvania Ave. NW, Suite 150 Washington, DC 20006 info@hyspeciq.com	**Hyperspectral;** forthcoming hyperspectral satellite constellation; initial deployment of 2 satellites scheduled for 2018
NorStar Space Data http://norstar-data.com/ 1000 Rue de la Gauchetiere Ouest, Suite 2400 Montreal, QC H3B 4W5 Canada	**Hyperspectral;** forthcoming 40 satellite constellation, with nadir viewing hyperspectral and infrared sensors for Earth observation and zenith viewing optical sensors for space situational awareness; deployment TBD
OmniEarth http://www.omniearth.net/ 251 18th Street South, Suite 650 Arlington, VA 22202 888.838.6318 **Lars Dyrud** President, CEO & Co-founder lars.dyrud@omniearth.net	**Multispectral;** forthcoming 18 satellite constellation, with 5-band multispectral + panchromatic; deployment scheduled for 2018 Also provides services for data analysis and analytics; specializes in image processing, data fusion, big data, and predictive analytics **Notes:** Dyrud presented at ISS R&D 2015
PlanetiQ http://www.planetiq.com/ 2425 55th St, Suite A-150 Boulder, CO 80301 571.364.7238	**Weather;** forthcoming 18 weather satellite constellation, with next generation radio occultation sensor; initial deployment of 12 satellites scheduled for 2017, with expansion to 18 satellites by 2020
Planet Labs https://www.planet.com/ 346 9th Street San Francisco, CA 94103 844.892.0786	**Multispectral;** planned 150-200 CubeSat satellite constellation, with 3-band multispectral; portion of constellation is currently operational, with 90+ satellites launched and 40+ operational as of Oct 2015; plans are to maintain 55 satellites in 52 degrees inclined orbit and 100-150 satellites in sun synchronous orbit **Multispectral;** recently acquired BlackBridge Group, which includes the RapidEye constellation of 5 identical satellites, each with 5-band multispectral Also provides an online platform for data access, analysis, and analytics; Planet Platform includes access to multispectral data from Planet Labs, RapidEye and Landsat

CONTACTS: COMMERCIAL EARTH OBSERVATION | SATELLITE	COMMENTS
Skybox Imaging (acquired by Google in 2014) http://www.skyboximaging.com/ 1061 Terra Bella Ave Mountain View, CA 94043	**Multispectral and video;** planned 24+ CubeSat satellite constellation with video and 4-band multispectral + panchromatic; initial 2 prototype satellites are operational Also provides an online platform for data access, analysis, and analytics that is sensor and data agnostic
Spire Global https://spire.com/ 33 Norfolk Street San Francisco, CA 94103 sf@spire.com 415.356.3400	**Weather;** forthcoming ~100 weather satellite constellation, with GPS-radio occultation sensors; initial 4 satellites deployed in 2015, with expansion of additional satellites TBD
Tempus Global Data http://www.tempusglobaldata.com/ 1146 South 7500 West Ogden, UT 84404 info@tempusglobaldata.com 801.560.1435	**Weather;** forthcoming 6 weather satellite constellation using hyperspectral sounders; initial deployment of first satellite in 2017 with 5 additional satellites launched at 6 month intervals
Urthecast https://www.urthecast.com/ 111 West Port Plaza, Suite 300 St. Louis, MO 63146 ***Phil Downen** VPGovernment Programs pdownen@urthecast.com 314.227.0370 (office) 636.426.0288 (mobile) ***Dave Welch** Software Engineer dwelch@urthecast.com 314.288.0532 (direct) 314.585.7422 (mobile) ***Hojin Kim** Remote Sensing Scientist hjkim@urthecast.com 314.403.7678 (direct) 215.203.2019 (mobile)	Earth observation data as a service, with a multispectral sensor (Theia) and ultra-HD video (Iris) already on ISS (currently operational); upcoming plans for a constellation of 16 satellites (8 dual-mode optical satellites, including video and multispectral, and 8 SAR satellites); initial satellite deployment scheduled 2017 **Notes:** Contacted Downen in-person at ISS R&D and Welch and Kim in-person at ENVI Analytics Symposium
Ursa Space Systems http://www.ursaspace.com/ 314 E State St, Suite 200 Ithaca, NY 14850 ***Julie Baker** Co-Founder 314 E State St, Suite 200 Ithaca, NY 14850 julie@ursaspace.com 607.279.1498	**SAR;** forthcoming SAR sensor on ISS (PolarISS) as well as proposed SAR satellite constellation utilizing unique low-cost SAR sensor system; deployments TBD **Notes:** Contacted Baker in-person at ENVI Analytics Symposium; company is recently funded by CASIS

SENSOR TECHNOLOGIES | HYPERSPECTRAL

CONTACTS: SENSOR TECHNOLOGIES | HYPERSPECTRAL	COMMENTS
BaySpec http://www.bayspec.com/ 1101 McKay Drive San Jose, CA 95131 408.512.5928	**Hyperspectral;** high-performance compact airborne hyperspectral imaging systems
Brandywine Photonics http://brandywinephotonics.com/ 748 Springdale Dr., Suite #125 Exton, PA 19341 484.459.9589 **John Fisher** Founder and President jfisher@brandywinephotonics.com 484.459.9589	**Hyperspectral;** spectrometers for airborne and space applications; responsible for optical design and spectrometer for HICO on ISS

CONTACTS: SENSOR TECHNOLOGIES | HYPERSPECTRAL	COMMENTS
Headwall Photonics http://www.headwallphotonics.com/ 601 River Street Fitchburg, MA 01420 978.353.4100	**Hyperspectral;** spaceflight and airborne imaging systems
Johns Hopkins University Applied Physics Laboratory http://www.jhuapl.edu/ 11100 Johns Hopkins Road Laurel, MD 20723 240.228.5201 **David Humm** Senior Staff Scientist CRISM Instrument Scientist david.humm@jhuapl.edu 240.228.6508	**Multiple sensor technologies, including hyperspectral;** spaceflight hardware and software systems; more than 64 spacecraft and 200 instruments; for example, CRISM instrument on Mars Reconnaissance Orbiter and New Horizons **Notes:** Humm is colleague of Goodman
NASA Jet Propulsion Laboratory http://www.jpl.nasa.gov/ 4800 Oak Grove Drive Pasadena, CA 91109 818.354.4321 **Robert Green** Senior Research Scientist, Principal, Fellow AVIRIS Experiment Scientist HyspIRI Mission Concept Co-Lead robert.o.green@jpl.nasa.gov 818.354.9136	**Multiple sensor technologies, including hyperspectral, LiDAR, SAR, and thermal;** spaceflight and airborne imaging systems; for example, ASTER, AVIRIS, ISS-RapidScat, MISR, SMAP, SRTM **Notes:** Green is colleague of Goodman
NovaSol http://www.nova-sol.com/ 1001 Bishop Street, Suite 2950 (headquarters) Honolulu, HI 96813 808.441.3600 12675 Danielsen Court, Suite 406 (optics) Poway, CA 92064 858.376.0185	**Hyperspectral;** turnkey imaging and navigation solutions, including real-time image processing; airborne imaging with some spaceflight experience; partner on development of HICO on ISS
Resonon http://www.resonon.com/ 123 Commercial Drive Bozeman, MT 59715 406.586.3356	**Hyperspectral;** low-cost compact airborne hyperspectral imaging systems

SENSOR TECHNOLOGIES | THERMAL

CONTACTS: SENSOR TECHNOLOGIES | THERMAL	COMMENTS
FLIR http://www.flir.com/home/ 27700 SW Parkway Ave (world headquarters) Wilsonville, OR 97070 503.498.3547	**Thermal;** largest commercial thermal imaging company with broad range of cameras, products, and applications; primarily ground and airborne applications; some space applicability RapidRecap video analysis technology analyzes video for unique events and embeds these events with timestamps into a single condensed video
NASA Jet Propulsion Laboratory http://www.jpl.nasa.gov/ 4800 Oak Grove Drive Pasadena, CA 91109 818.354.4321 **Robert Green** Senior Research Scientist, Principal, Fellow AVIRIS Experiment Scientist HyspIRI Mission Concept Co-Lead robert.o.green@jpl.nasa.gov 818.354.9136	Multiple sensor technologies, including hyperspectral, LiDAR, SAR, and thermal; spaceflight and airborne imaging systems; for example, ASTER, AVIRIS, ISS-RapidScat, MISR, SMAP, SRTM **Notes:** Green is colleague of Goodman
Sierra-Olympic Technologies http://www.sierraolympic.com/ 3100 Cascade Avenue Hood River, OR 97031 855.222.1801	**Thermal;** airborne and ground-based thermal imaging systems

SENSOR TECHNOLOGIES | LIDAR

CONTACTS: SENSOR TECHNOLOGIES | LIDAR	COMMENTS
Astra http://www.astraspace.net/ 5777 Central Ave., Suite 221 Boulder, CO 80301 303.993.8039	Multiple technologies, including space weather, miniaturized space-science systems for CubeSats, and LiDAR; ground and space based instruments; partnership with Orbital ATK for hosted payloads
Fibertek http://www.fibertek.com/ 13605 Dulles Technology Drive Herndon, VA 20171 703.471.7671	**LiDAR;** solid-state sensors and electro-optical sensors for military and space applications; five laser systems in space: CALIOP (CALIPSO) and upcoming CATS and ATLAS (ICESat-2)
NASA Jet Propulsion Laboratory http://www.jpl.nasa.gov/ 4800 Oak Grove Drive Pasadena, CA 91109 818.354.4321 **Robert Green** Senior Research Scientist, Principal, Fellow AVIRIS Experiment Scientist HyspIRI Mission Concept Co-Lead robert.o.green@jpl.nasa.gov 818.354.9136	Multiple sensor technologies, including hyperspectral, LiDAR, SAR, and thermal; spaceflight and airborne imaging systems; for example, ASTER, AVIRIS, ISS-RapidScat, MISR, SMAP, SRTM **Notes:** Green is colleague of Goodman
RIEGL USA http://www.rieglusa.com/ 7035 Grand National Drive, Suite 100 Orlando, FL 32819 407.248.9927	**LiDAR;** unmanned, airborne, mobile, and terrestrial LiDAR, including system integration, training and support
SigmaSpace http://www.sigmaspace.com/ 4600 Forbes Boulevard Lanham, MD 20706 301.552.6000	**LiDAR;** specifically, high-efficiency single-photon LiDAR systems; airborne with stated potential for spaceflight
Teledyne Optech (formerly Optech Inc) http://www.teledyneoptech.com/ 300 Interchange Way (corporate headquarters) Vaughan, Ontario L4K 5Z8 905.660.0808 7225 Stennis Airport Road (USA Mississippi) Kiln, MS 39556 228.252.1004 150 Lucius Gordon Drive W. (USA New York) Henrietta, NY 14586 585.427.8310	**LiDAR;** airborne imaging systems, including bathymetric LiDAR, as well as space-proven sensors
Velodyne LiDAR http://velodynelidar.com/ 345 Digital Drive Morgan Hill, CA 95037 408.465.2800	**LiDAR;** provides full line of UAV, robotic, automotive, and marine LiDAR sensors capable of delivering real-time 3D data

SENSOR TECHNOLOGIES | SAR

CONTACTS: SENSOR TECHNOLOGIES | SAR	COMMENTS
Artemis http://artemisinc.net/ 36 Central Avenue Hauppauge, NY 11788 631.232.2324	**SAR;** airborne and space platforms; stripmap SAR, circular SAR; high-resolution SAR, multi-frequency imaging, polarimetric SAR, interferometry
Imsar http://imsar.com/ 940 South 2000 West, #140 Springville, UT 84663 801.798.8440	**SAR;** airborne imaging and real-time processing; world's smallest SAR

CONTACTS: SENSOR TECHNOLOGIES | SAR	COMMENTS
NASA Jet Propulsion Laboratory http://www.jpl.nasa.gov/ 4800 Oak Grove Drive Pasadena, CA 91109 818.354.4321 **Robert Green** Senior Research Scientist, Principal, Fellow AVIRIS Experiment Scientist HyspIRI Mission Concept Co-Lead robert.o.green@jpl.nasa.gov 818.354.9136	Multiple sensor technologies, including hyperspectral, LiDAR, SAR, and thermal; spaceflight and airborne imaging systems; for example, ASTER, AVIRIS, ISS-RapidScat, MISR, SMAP, SRTM Notes: Green is colleague of Goodman
Nuvotronics http://www.nuvotronics.com/ 2305 Presidential Drive (headquarters) Durham, NC 27703 800.341.2333 7586 Old Peppers Ferry Loop (Virginia facility) Radford, VA 24141 100 Tradecenter, Suite 761 (Massachusetts Facility) Woburn, MA 01801	**SAR and radar;** components, instruments, and sensor solutions, including innovative manufacturing processes and facilities
Sandia National Labs http://www.sandia.gov/radar/ 1515 Eubank SE Albuquerque, NM 87123 505.844.8066 Jon Chavez Business Development jonchav@sandia.gov 505.844.3179	**SAR;** more than 30 years of experience in SAR development; focus on airborne platforms, but also includes experience in space applications
SRC http://www.srcinc.com/what-we-do/radar-and-sensors/ 7502 Round Pond Road (headquarters) North Syracuse, NY 13212 315.452.8000	**SAR and radar;** airborne applications; high performance computing and real-time imaging

SUPPORTING TECHNOLOGIES | COMPONENTS/SENSORS

CONTACTS: SUPPORTING TECHNOLOGIES | COMPONENTS/SENSORS	COMMENTS
Alliance Spacesystems http://www.alliancespacesystems.com/ 4398 Corporate Center Drive Los Alamitos, CA 90720 714.226.1400 **Markham Hacke** Business Development mhacke@alliancespacesystems.com 714.226.1404	**Satellite and launch vehicle structures,** including payload, bus, optical and thermal coatings, optical packages, antennas and phased array structures, and electrical harnesses, among others; also solar power solutions
Dartmouth College, Thayer School of Engineering http://engineering.dartmouth.edu/ 14 Engineering Drive Hanover, NH 03755 603.646.2230 **Eric Fossum** Professor of Engineering eric.r.fossum@dartmouth.edu	**Quanta Image Sensors;** major paradigm shift in image capture; still under development **Note:** Fossum is inventor of CMOS active pixel image sensor
e2v http://www.e2v-us.com/ 765 Sycamore Drive (headquarters) Milpitas, CA 95035 408.737.0992 1302 E. Collins Blvd., Suite 200 (engineering, product development) Richardson, TX 75081 404.240.5211	**CMOS, CCD, and EMCCD imaging sensors, arrays, and cameras;** experience in high-profile large-scale space missions
HNu Photonics http://www.hnuphotonics.com/ 350 Hoohana Street Kahului, HI 96732 808.244.7800	**Optics, telescopes, and spectral calibration;** imaging and laser technologies, including flash hyper-dimensional imaging; optics design, fabrication, and testing

SUPPORTING TECHNOLOGIES | ANALYTICS/SOFTWARE

CONTACTS: SUPPORTING TECHNOLOGIES | ANALYTICS/SOFTWARE	COMMENTS
Astro Digital (partnered with Aquila Space) https://astrodigital.com/ NASA Ames Research Park Moffett Field, CA 94035 hello@astrodigital.com	**Online platform for data access, analysis, and analytics;** provides online data access and image processing tools for multispectral Landsat imagery as well as the upcoming multispectral 30 satellite constellation from Aquila Space
DigitalGlobe https://www.digitalglobe.com/ 1300 W. 120th Ave (headquarters) Westminster, CO 80234 800.655.7929 303.684.4000	**Online platform for data access, analysis, and analytics;** Geospatial Big Data Platform provides access to DigitalGlobe's 15 years of satellite imagery – 70 petabytes – within a user configurable cloud computing platform Leading global provider of commercial high resolution multispectral Earth imagery products and services
FLIR http://www.flir.com/home/ 27700 SW Parkway Ave (world headquarters) Wilsonville, OR 97070 503.498.3547	**Video analysis;** RapidRecap technology analyzes video for unique events and embeds these events with timestamps into a single condensed video Largest commercial thermal imaging company with broad range of cameras, products, and applications
HySpeed Computing http://www.hyspeedcomputing.com/ PO Box 431824 Miami, FL 33243 305.302.2324 ***James Goodman** President/CEO PO Box 431824 Miami, FL 33243 jgoodman@hyspeedcomputing.com 305.302.2324	**Data analysis and analytics, and software and application development, including cloud computing and high performance algorithm acceleration** **Notes:** CASIS funded research; Goodman is author of Good Earth Gap Analysis
OmniEarth http://www.omniearth.net/ 251 18th Street South, Suite 650 Arlington, VA 22202 888.838.6318 **Lars Dyrud** President, CEO & Co-founder lars.dyrud@omniearth.net	**Data analysis and analytics;** specializes in image processing, data fusion, big data, and predictive analytics Plans for forthcoming multispectral 18 satellite constellation; deployment scheduled for 2018 **Notes:** Dyrud presented at ISS R&D 2015
Orbital Insight http://orbitalinsight.com/ 410 Cambridge Avenue First Floor Palo Alto, CA 94306	**Data analysis and analytics;** creating market intelligence through image analysis for decision makers and investors in a wide range of industries
Planet Labs https://www.planet.com/ 346 9th Street San Francisco, CA 94103 844.892.0786	**Online platform for data access, analysis and analytics;** recently released beta version of Planet Platform, a developers sandbox with access to image analysis tools and multispectral data from Planet Labs, RapidEye, and Landsat Also operates an expanding constellation of multispectral CubeSats; plans are to maintain 55 satellites in 52 degrees inclined orbit and 100-150 satellites in sun synchronous orbit Recently acquired BlackBridge Group, which includes the RapidEye constellation of 5 identical multispectral satellites
RS Metrics https://www.rsmetrics.com/ 3046 N. Sheffield Ave. (headquarters) Chicago, IL 60657 **Tom Diamond** President and Co-founder 200 West Madison St., Suite 1940 Chicago, IL 60606 tdiamond@rsmetrics.com 312.424.4001	**Data analysis and analytics;** generating investment and business intelligence through quantitative analysis of high-resolution satellite imagery
Skybox Imaging (acquired by Google in 2014) http://www.skyboximaging.com/ 1061 Terra Bella Ave Mountain View, CA 94043	**Online platform for data access, analysis, and analytics;** offers a scalable data analysis platform that is sensor and data agnostic, which means users can utilize Skybox's data and algorithms or upload their own content Also includes planned multispectral and video 24+ CubeSat satellite constellation; initial 2 prototype satellites are operational

CONTACTS: SUPPORTING TECHNOLOGIES | ANALYTICS/SOFTWARE	COMMENTS
Spaceknow https://spaceknow.com/ 620 Folsom St. San Francisco, CA 94107 **Pavel Machalek** CEO insights@spaceknow.com 443.824.0877	**Data analysis and analytics;** provides integrated data access to multiple data providers, data analytics, and business intelligence solutions
The HDF Group https://www.hdfgroup.org/ 1800 S. Oak St., Suite 203 Champaign, IL 61820 217.531.6100 ***Ted Habermann** Director, Earth Sciences 1800 S. Oak St., Suite 203 Champaign, IL 61820 thabermann@hdfgroup.org 217.531.4202	**Data management and format;** provides technologies for managing, storing, and accessing large and complex data collections **Notes:** Contacted Haberman in-person at ENVI Analytics Symposium

SUPPORTING TECHNOLOGIES | PROCESSING HARDWARE

CONTACTS: SUPPORTING TECHNOLOGIES | PROCESSING HARDWARE	COMMENTS
Business Integra http://businessintegra.com/ 6550 Rockledge Dr., Suite 450 Bethesda, MD 20817 301.474.9600 ***Trent Martin** Senior Director of Houston Operations 2224 Bay Area Blvd. Houston, TX 77058 trent.martin@businessintegra.com 281.816.6221 x141 (office) 281.961.7734 (mobile)	**Geospatial data processing hardware and services;** cloud computing; big data analytics **Notes:** Telecon w/ CASIS and Martin
ViON http://www.vion.com/ 196 Van Buren Street, Suite 300 Herndon, VA 20170 571.353.6071 ***Rick Elsbury** Product Manager, Big Data Solutions rick.elsbury@vion.com 571.353.6149 (office)	**Ground-based data processing solutions;** provides turnkey data storage and data processing systems; interested in exploring options in remote sensing cloud computing **Notes:** Contacted Elsbury in-person at ENVI Analytics Symposium

ADDITIONAL | MCKINSEY & COMPANY REPORT

CONTACTS: ADDITIONAL | MCKINSEY & COMPANY REPORT	INTEREST
Google Maps Business Development **Birju Shah** birjus@gmail.com	Interested in discussing opportunities to partner and gather data for Google Maps
Norway's International Climate and Forest Initiative Oslo, Norway **Maarten van der Eynden** marten-van-der.Eynden@md.dep.no +47.926.14.669 +47.22.24.58.89	Interested in discussing unmet needs for data to confirm and monitor global forest conservation to validate and protect $500M/year investment

[8]*http://sbir.nasa.gov/solicit-detail/54565*

CONTACTS: ADDITIONAL | MCKINSEY & COMPANY REPORT	INTEREST
Rensselaer Polytechnic Institute Troy, NY **Jon Morse, Ph.D.** jmorse@rpi.edu 518.276.2542	Strong interest in discussing interest of academic community, particularly astrophysics and astronomy, and foundational support for ISS remote sensing
University of Maryland, Department Geographical Sciences College Park, MD **Ralph Dubayah, Ph.D.** dubayah@umd.edu	Very strong interest in space-based LiDAR for conservation and climate change purposes; open to partnerships with commercial entities; author of several space-based LiDAR proposals
Woods Hole Research Center Falmouth, MA **Alessandro Baccini, Ph.D.** abaccini@whrc.org	Works in the forestry department; has numerous ties to the community and interest in connecting you to others with interest

ADDITIONAL | CASIS AEROSPACE INDUSTRY PARTNERS

CONTACTS: ADDITIONAL | CASIS AEROSPACE INDUSTRY PARTNERS
Aerospace Corporation El Segundo, CA (Los Angeles) **Wanda Austin** – CEO **Glenn Davis** – Vice President Strategic Space Operations **Ed Swallow** – Vice President Civil and Commercial Operations – edward.m.swallow@aero.org
ATK (Orbital) Cape Canaveral, FL **Frank Culbertson** – Senior Vice President, Deputy General Manager **Charlie Precourt** – VP and GM Space Launch Systems **Arnie Streland** – Senior Director, Strategy and Business Development – arnie.streland@aol.com
Ball Aerospace Boulder, CO **Jim Oschmann** – Vice President and General Manager Civil Space & Technology
Blue Origin Kent, WA (Seattle) **Rob Meyerson** · President
Boeing Satellite Systems Kent, WA (Seattle) **Major General (Ret) Craig Cooning** – President, Network and Space Systems, Defense, Space & Security
Gencorp (Aerojet/Rocketdyne) Rancho Cordova, CA (Sacramento) **Eileen Drake** – CEO (former Vice President of Operations at United Technologies/Pratt & Whitney)
Harris Melbourne, FL **Bill Gattle** – President Space & Intelligence Solutions
L-3 Communication TBD
Lockheed Martin Commercial Space **Lt. General (Ret) Michael Hamel** – President of Commercial Ventures
Lockheed Martin Space Systems Sunnyvale, CA (San Francisco) **Rick Ambrose** – Executive Vice President

CONTACTS: ADDITIONAL | CASIS AEROSPACE INDUSTRY PARTNERS
Lockheed Martin Space Technology Advanced Research and Development Laboratories (STAR Labs) Palo Alto, CA (San Francisco) **Rick Ambrose** – Executive Vice President
Moog TBD
Northrop Grumman Redondo Beach, CA (Los Angeles) **Jeff Grant** – Sector Vice President and General Manager, Space Systems
Raytheon El Segundo, CA (Los Angeles) TBD
Riverside Research (Applied Research Solutions) Dayton, OH **Kevin Sullivan** · President
Rocket Lab Auckland, New Zealand **Peter Beck** · CEO
Surrey Satellites US LLC Englewood, CO **John Paffett** · CEO
Teledyne Brown Engineering Huntsville, AL **John Horack** – Vice President Global Commercial Space
USAF/SMC – NRO Chantilly, VA (Washington DC) Major General (S) **Major General Anthony J. Cotton** – (June 2013 – November 2015) **Major General Stephen T. Denker** – Deputy Director (Current)

TECHNOLOGY READINESS LEVELS

For reference, a summary is included here of the NASA Technology Readiness Level definitions as presented in NASA's most recent Small Business Innovation Research (SBIR) guidelines:

"The Technology Readiness Level (TRL) describes the stage of maturity in the development process from observation of basic principles through final product operation. The exit criteria for each level documents that principles, concepts, applications or performance have been satisfactorily demonstrated in the appropriate environment required for that level. A relevant environment is a subset of the operational environment that is expected to have a dominant impact on operational performance. Thus, reduced-gravity may be only one of the operational environments in which the technology must be demonstrated or validated in order to advance to the next TRL."[8]

TRL	DEFINITION	HARDWARE DESCRIPTION	SOFTWARE DESCRIPTION	EXIT CRITERIA
1	Basic principles observed and reported.	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	Technology concept and/or application formulated.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Practical application is identified but is speculative; no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.
3	Analytical and experimental critical function and/or characteristic proof of concept	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experimental results validating predictions of key parameters.
4	Component and/or breadboard validation in laboratory environment.	A low-fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant environments defined and performance in this environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Component and/or breadboard validation in relevant environment.	A medium-fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrate overall performance in critical areas. Performance predictions are made for subsequent development phases.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.

TRL	DEFINITION	HARDWARE DESCRIPTION	SOFTWARE DESCRIPTION	EXIT CRITERIA
6	System/subsystem model or prototype demonstration in a relevant environment.	A high-fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrated with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.
7	System prototype demonstration in an operational environment.	A high-fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test performance demonstrating agreement with analytical predictions.
8	Actual system completed and “flight qualified” through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne, or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation (V&V) completed.	Documented test performance verifying analytical predictions.
9	Actual system flight proven through successful mission operations.	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results.

SELECT REFERENCES

- Barker, DC, 2012, International Space Station Facilities, Research in Space 2013 and Beyond, National Aeronautics and Space Administration, Johnson Space Center, NASA/NP-2012-10-027-JSC.

- Burks J, Molthan A, Zavodsky B, Irwin D, Limaye A, 2015, NASA Marshall Space Flight Center Research to Application Paradigms, SPoRT & SERVIR Success Stories, Data Fusion and Humanitarian Applications, National Aeronautics and Space Administration, Marshall Space Flight Center, presentation to National Geographic June 2015.

- Hornyak DM, 2013, A Researcher's Guide to: International Space Station Technology Demonstration, National Aeronautics and Space Administration, Johnson Space Center, NASA/NP-2013-06-008-JSC.

- McKinsey & Company, 2013, Maximizing the Value of CASIS Platform – Remote Sensing.

- NASA, 2015, External Payloads Proposer's Guide to the International Space Station, Change 01, National Aeronautics and Space Administration, Goddard Space Flight Center, GSFC 420-01-09.

- NASA, 2015, Reference Guide to the International Space Station Utilization Edition, National Aeronautics and Space Administration, NASA/NP-2015-05-022-JSC.

- NASA, 2009, Plan to Support Operations and Utilization of the International Space Station Beyond FY 2015 pursuant to Section 601 of the NASA Authorization Act of 2008 (P.L. 110-422), National Aeronautics and Space Administration.

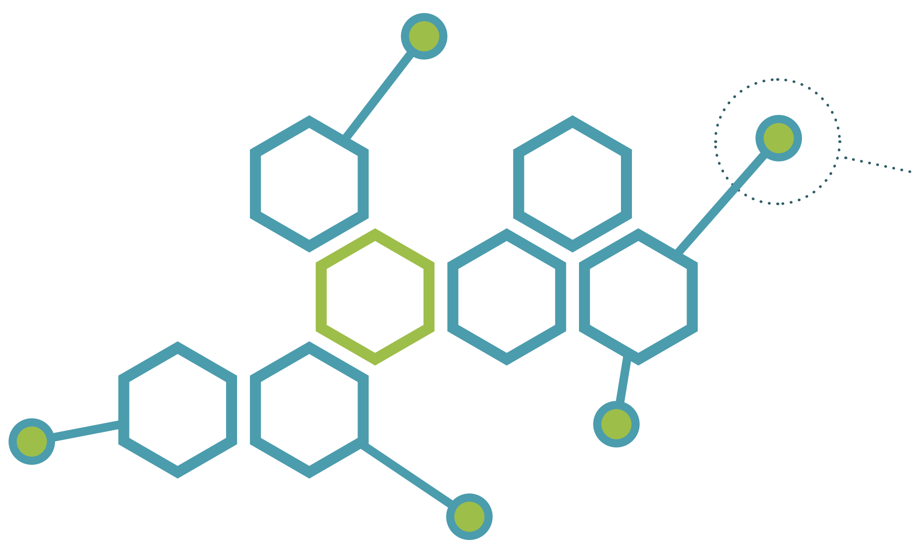
- NASA, 2006, The National Aeronautics and Space Administration (NASA) Research and Utilization Plan for the International Space Station (ISS), A Report to the Committee on Science of the United States House of Representatives and the Committee on Commerce, Science, and Transportation of the United States Senate, National Aeronautics and Space Administration.

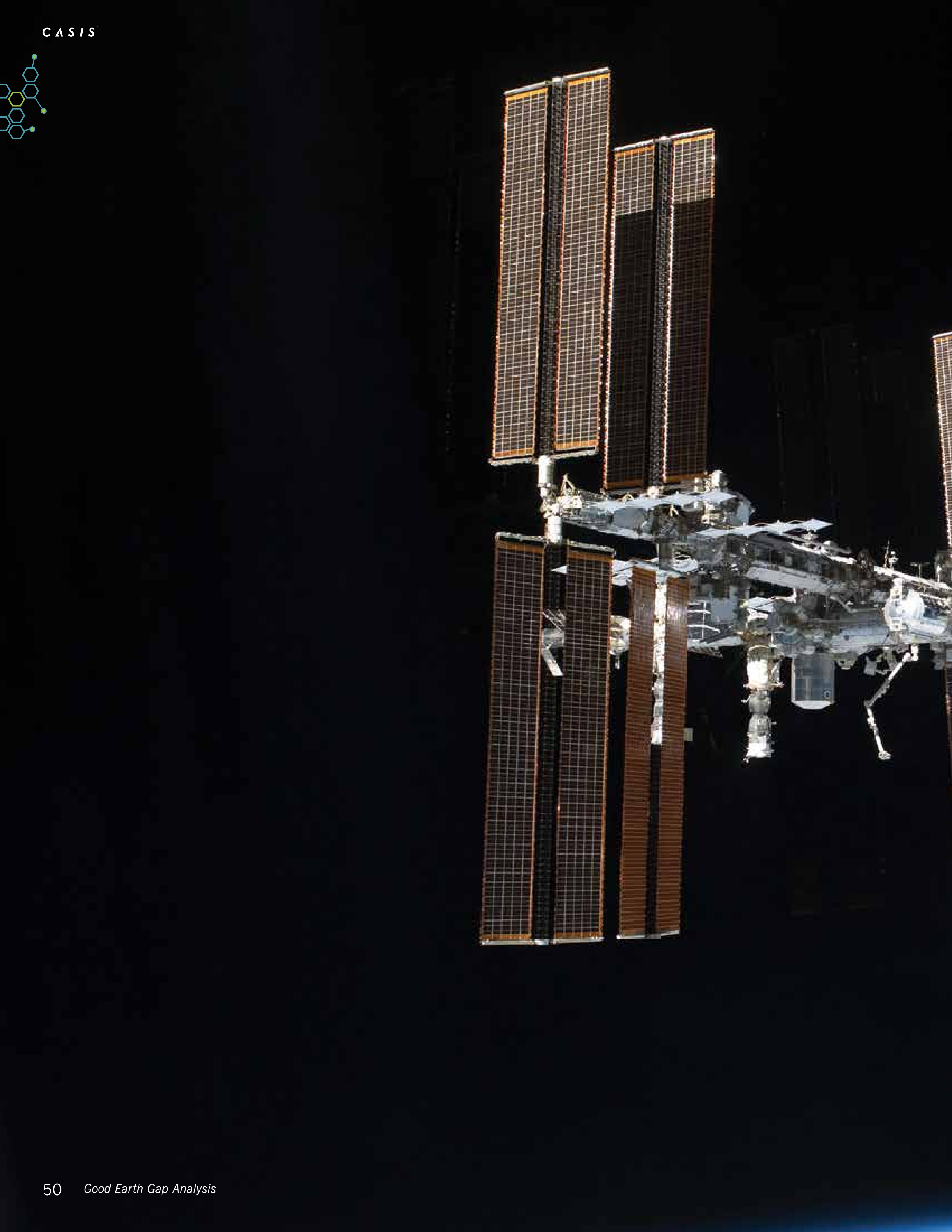
- Robinson JA, Rai A, et al., 2015, International Space Station Benefits for Humanity, Second Edition, National Aeronautics and Space Administration, Canadian Space Agency, European Space Agency, Japan Aerospace Exploration Agency, Russian Federal Space Agency, Italian Space Agency, NASA/NP-2015-01-001-JSC.

- Robinson JA, Thumm TL, et al, 2012, International Space Station Benefits for Humanity, National Aeronautics and Space Administration, Canadian Space Agency, European Space Agency, Japan Aerospace Exploration Agency, Russian Federal Space Agency, NASA/NP-2012-02-003-JSC.

- Stefanov WL, 2015, ISS: A Unique Platform for Earth Observation, National Aeronautics and Space Administration, Johnson Space Center, presentation to National Geographic June 2015.

- Vanderbloemen LA, Stefanov WL, Evans CA, 2013, A Researcher's Guide to: International Space Station Earth Observations, National Aeronautics and Space Administration, Johnson Space Center, NASA/NP-2013-06-011-JSC.





CASIS™

www.iss-casis.org