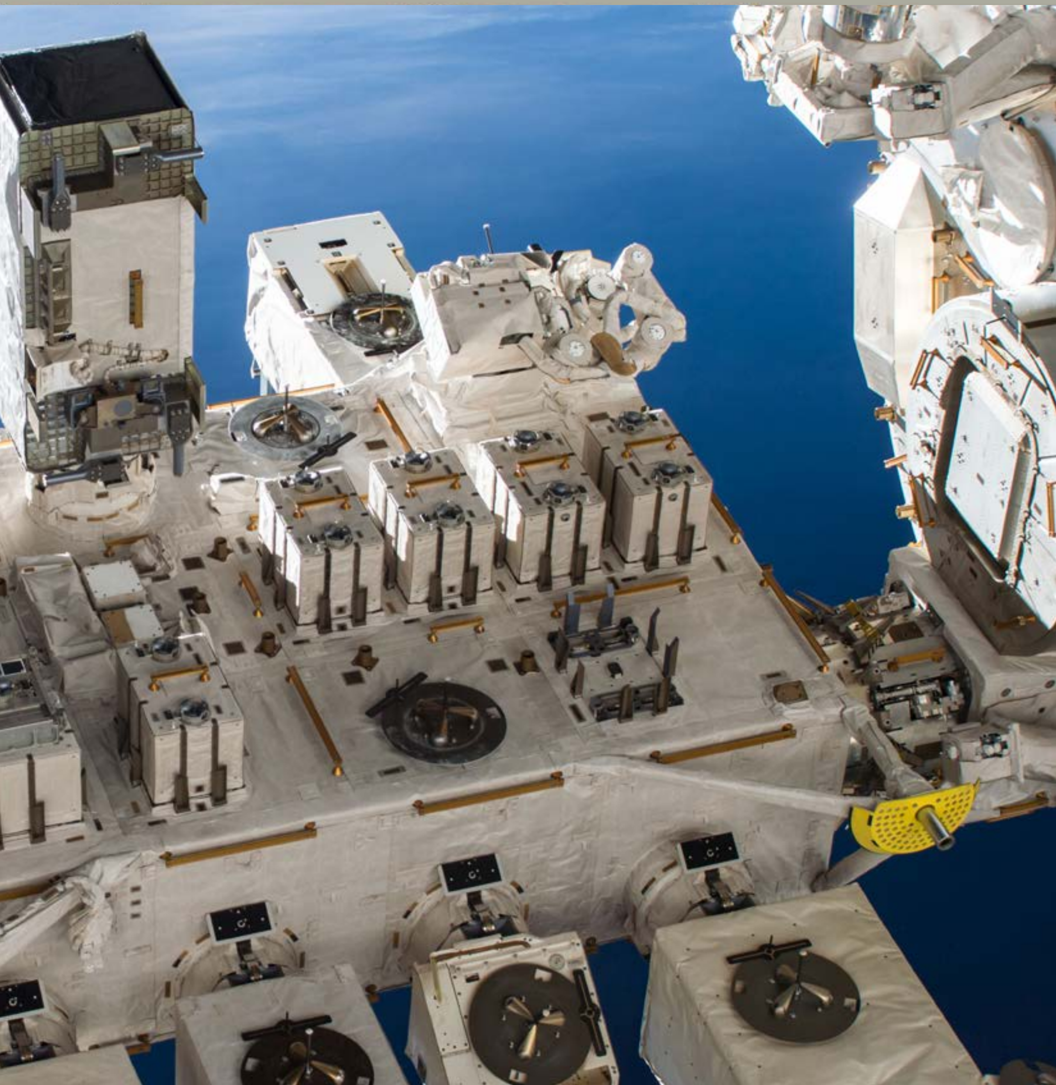
National Aeronautics and Space Administration

A Researcher's Guide to:

INTERNATIONAL SPACE STATION

Earth Observations



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Cover and back cover:

a. Photograph of the Japanese Experiment Module Exposed Facility (JEM-EF). This photo was taken using External High Definition Camera (EHDC) 1 during Expedition 56 on June 4, 2018.

b. Photograph of the Momotombo Volcano taken on July 10, 2018. This active stratovolcano is located in western Nicaragua and was described as "the smoking terror" in 1902. The geothermal field that surrounds this volcano creates ideal conditions to produce thermal renewable energy.

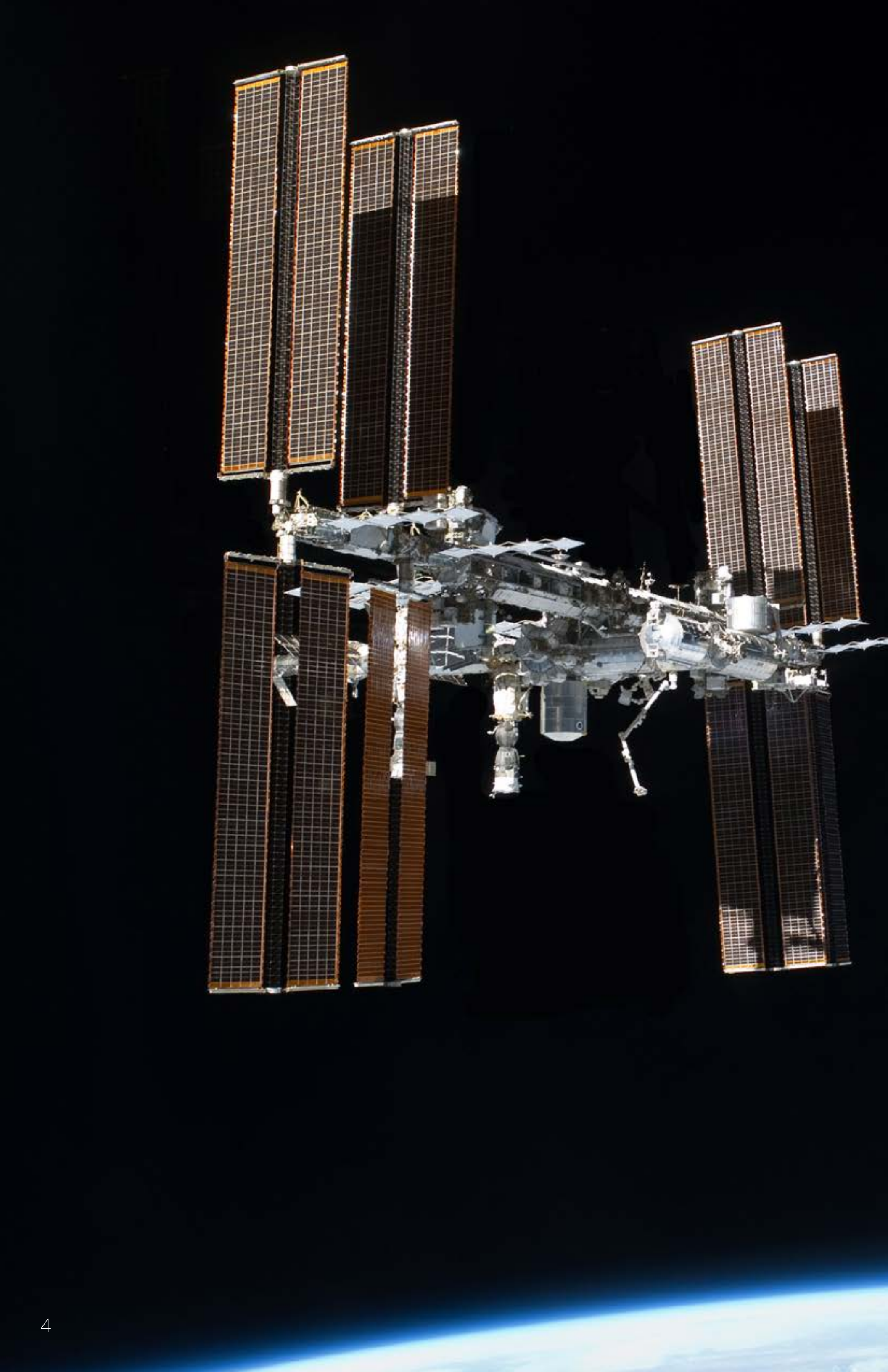
c. Photograph of the Betsiboka River Delta in Madagascar taken on June 29, 2018. This river is comprised of interwoven channels carrying sediment from the mountains into Bombetoka Bay and the Mozambique Channel. The heavy islands of built-up sediment were formed as a result of heavy deforestation on Madagascar since the 1950s.

The Lab is Open

Orbiting the Earth at almost 5 miles per second, a structure exists that is nearly the size of a football field and weighs almost a million pounds. The International Space Station (ISS) is a testament to international cooperation and significant achievements in engineering. Beyond all of this, the ISS is a truly unique research platform. The possibilities of what can be discovered by conducting research on the ISS are endless and have the potential to contribute to the greater good of life on Earth and inspire generations of researchers to come.

As we fully utilize ISS as an international laboratory, now is the time for investigators to propose new research and to make discoveries unveiling novel responses that cannot be defined using traditional approaches on Earth.

These circular star trails and the rainbow of colorful lights on the Earth below them were created by combining 18 images with prolonged exposures into a composite photo. The bluish-white specks in the foreground that appear similar to balls of cotton are lightning from storms on Earth. This image depicts one of the many creative ways users of the International Space Station can observe the wonder of the Earth below, the vast expanse of space and its many stars beyond. From this vantage point, we seek to understand the origins and composition of our universe.



Unique Features of the ISS Research Environment

1. **Microgravity**, or weightlessness, alters many observable phenomena within the physical and life sciences. Systems and processes affected by microgravity include surface wetting and interfacial tension, multiphase flow and heat transfer, multiphase system dynamics, solidification, and fire phenomena and combustion. Microgravity induces a vast array of changes in organisms ranging from bacteria to humans, including global alterations in gene expression and three-dimensional aggregation of cells into tissue-like architecture.

2. **Extreme conditions** in the ISS environment include exposure to extreme heat and cold cycling, ultra-vacuum, atomic oxygen, and high-energy radiation. Testing and qualification of materials exposed to these extreme conditions have provided data to enable the manufacturing of long-life reliable components used on Earth as well as in the world's most sophisticated satellite and spacecraft components.

3. **Low-Earth orbit** at 51.6 degrees inclination with a 90-minute orbit affords the ISS a unique vantage point with an altitude of approximately 249 miles (400 kilometers) and an orbital path over 90 percent of the Earth's population. This flight path can provide improved spatial resolution and variable lighting conditions compared to the sun-synchronous orbits of typical Earth remote-sensing satellites.

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Why Use ISS as a Remote Sensing Platform?

According to the current Science Plan for the National Aeronautics and Space Administration (NASA) Science Mission Directorate, the following are the priority Science Questions and Goals for Earth Science.

Science Questions

- How is the global Earth system changing?
- What causes these changes in the Earth system?
- How will the Earth system change in the future?
- How can Earth system science provide societal benefit?

Science Goals

- Advance the understanding of changes in the Earth's radiation balance, air quality and the ozone layer that result from changes in atmospheric composition (Atmospheric Composition)
- Improve the capability to predict weather and extreme weather events (Weather)
- Detect and predict changes in Earth's ecosystems and biogeochemical cycles, including land cover, biodiversity, and the global carbon cycle (Carbon Cycle and Ecosystems)
- Enable better assessment and management of water quality and quantity to accurately predict how the global water cycle evolves in response to climate change (Water and Energy Cycle)
- Improve the ability to predict climate changes by better understanding the roles and interactions of the ocean, atmosphere, land and ice in the climate system (Climate Variability and Change)
- Characterize the dynamics of Earth's surface and interior, improving the capability to assess and respond to natural hazards and extreme events (Earth Surface and Interior)
- Further the use of Earth system science research to inform decisions and provide benefits to society

The Earth is a complex, dynamic system we do not yet fully understand. The Earth system, like the human body, is comprised of diverse components that interact in complex ways. In order to answer the above questions and address the objectives, we need to understand the Earth's atmosphere, lithosphere, hydrosphere, cryosphere, and biosphere as contributing elements of a single connected system. Our planet is changing on all spatial and temporal scales. The purpose of NASA's

Earth science program is to advance our scientific understanding of Earth as a system and its response to natural and human-induced changes and to improve our ability to predict climate, weather, and natural hazards.

A major component of NASA's Earth Science Division is a coordinated series of satellite and airborne missions for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. This systematic approach allows for a better understanding of the Earth as an integrated system. NASA continues to develop and launch foundational missions, new decadal survey missions, and Climate Continuity missions. The ISS provides unique capabilities and offers new opportunities for remote-sensing research and applications.

Advantages and Challenges to Earth Observations from the ISS

While NASA and other space agencies have had remote-sensing systems orbiting Earth and collecting publically available data since the early 1970s, these sensors have been primarily carried aboard free-flying unmanned satellites. These satellites have typically been placed into sun-synchronous polar orbits that allow for repeat imaging of the entire surface of the Earth with approximately the same sun illumination (typically local solar noon) over specific areas with set revisit times. This data collection process allows uniform data to be taken over long time periods and enables straightforward analysis of change over time.

The ISS is a remote sensing platform that is unique from several perspectives: unlike automated remote-sensing platforms, it has a human crew, a low-orbit altitude, and orbital parameters that provide variable views and lighting. The presence of a crew provides options not available to robotic sensors and platforms such as the ability to collect unscheduled data of an unfolding event using handheld digital cameras as part of the Crew Earth Observations facility and real-time assessment of whether environmental conditions (such as cloud cover) are favorable for data collection. The crew can also swap out internal sensor systems and payloads installed in the Window Observational Research Facility (WORF) on an as-needed basis.

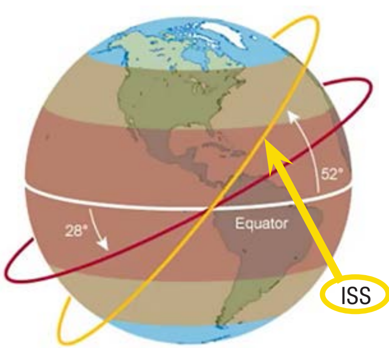
ISS Orbital Parameters

The ISS has an inclined, sun-asynchronous orbit (the solar illumination for data collection over any location changes as the Earth's orbit precesses) that carries it over locations on the Earth between the latitudes 51.6 degrees North and 51.6 degrees South.

The ISS orbit has an average altitude of 400 km (about 249 miles) above sea level. Because of atmospheric drag, reboosting of the ISS to maximum altitude is required approximately every 90 days. Due to the westward precession of orbit tracks, the ISS has an approximate repeat time over the same location every three to four days with similar lighting conditions repeated on an approximately 63-day cycle at the equator, not correcting for seasonal lighting shifts (Stefanov et al. 2017).

The ISS orbit covers over 90 percent of the inhabited surface of the Earth and allows the ISS to pass over ground locations at different times of the day and night.

This orbital plane is important for two main reasons:



Most NASA satellites orbit over the poles, but the International Space Station's orbit is inclined 51.6°, which allows for imaging of approximately 90 percent of the Earth's populated surface. Shuttle missions launching from NASA's Kennedy Space Center often launched with a 28.5° inclination.

1) Certain surface and atmospheric processes have time variable characteristics that change throughout the day or occur at times other than a fixed equator crossing time (for example, development of coastal fog banks), making relevant data difficult to collect from sun-synchronous satellite platforms.

2) With the appropriate targeting or pointing systems, the ISS orbit provides opportunities for sensors to collect data for short-duration events, such as natural disasters, that polar-orbiting satellites may miss because of their orbital dynamics.

In essence, the ISS can be "in the right place and at the right time" to collect data (Stefanov and Evans 2015; Gebelein and Eppler 2007). These capabilities enable ISS data to be complimentary to polar-orbiting satellite data.

Results from Past Research

Early Remote Sensing from Crew-Tended Platforms (pre-ISS)

NASA has a long legacy of remote sensing from space over more than 50 years. During the unmanned Mercury test flights of the late 1950s, hundreds of photographs were taken and have proven useful to the scientific community. In the early 1960s, approximately 55 handheld photographs were taken during the four manned Mercury flights. During the 10 manned flights of the Gemini Program (1963-1966), about 2,400 photos were taken. During the Apollo Program (1961-1972), stereoscopic frames were taken from space for the first time. During the Apollo missions, investigators also verified the concept of applying multi-spectral, multi-temporal imagery from space to vegetation mapping and to the monitoring of land use. During the three manned Skylab missions (1973-1974), Earth resources research efforts were performed. The Earth Resources Experiment Package (EREP) consisted of a complex set of tests involving multiple onboard instruments (cameras, a multispectral scanner, spectrometer, and microwave devices) in conjunction with field investigations and aerial remote-sensing flights and hundreds of scientists (Amsbury 1989). These efforts led directly to the development of unmanned satellite-based remote-sensing systems (e.g., the Landsat series) that continue to form the core of NASA's ability to examine and monitor the Earth system from space (Green and Jackson 2009).

During the Space Shuttle Program (1981-2011), space photography continued in addition to other scientific experiments. On two missions (April/October 1994), the Spaceborne Imaging Radar-C/X-Band (SIR-C/X) Synthetic Aperture Radar (SAR) was flown. This was the most advanced civilian SAR ever built, providing the first multi-frequency data sets from space. The data provided a wealth of information about the Earth's changing environment while opening up new areas of potential use for spaceborne imaging radar data to include natural-hazard assessments. On February 11, 2000, the Shuttle Radar Topography Mission (SRTM) payload aboard Space Shuttle Endeavour launched into space. SRTM acquired enough data during its 10 days of operation to obtain the first-ever, near-global, high-resolution dataset of the Earth's topography, covering nearly 80 percent of the Earth's land surface (Farr et al. 2007).

The Shuttle-Mir (1995-1998) Program was a collaborative program between the United States and the USSR/Russia. During its nine missions, over 22,000 Earth images were taken that documented long-term study sites and dynamic events on the Earth's surface. These events included land use change, seasonal change and long-term climate change, atmospheric events, ocean and coastal dynamic features, volcanoes, and cities/regional sites (Evans, et al. 2000; Stefanov, et al. 2017).

Earth Science Research on ISS

The ISS was first inhabited in November 2000. This laboratory in space has continuously grown and supports multi-discipline research.

In 2009, a significant space exploration goal was reached when the number of astronauts capable of living aboard the ISS increased from three to six. In 2011, the assembly of the ISS was completed. Since then, the time spent performing ISS research has continuously increased. ISS laboratories now accommodate an unprecedented amount of space-based research with new and exciting capabilities being continuously proposed and developed. This Earth-orbiting laboratory and living facility houses astronauts who continuously conduct science across a wide variety of fields including the Earth sciences. In addition to crew-tended experiments, the ISS also provides a variety of internal and external mounting locations, and common data transfer and power interfaces, that facilitate its use for automated remote-sensing systems.

For up-to-date information regarding ISS research activities and accomplishments (including Earth science), please visit https://www.nasa.gov/mission_pages/station/research/experiments/explorer/.

Opportunities for Research

The International Space Station (ISS) provides a unique platform to view and study the Earth from space by supporting crew-operated and ground-commanded sensor systems. Multiple instruments, both mounted externally and operated from inside the Station, are used to collect data on the Earth's oceans, atmosphere, and land surface.

This Researcher's Guide includes information on past, current, and planned ISS Earth observation systems. We have included citations to published results, reports, presentations, etc. when relevant and available, but for some systems, including those newly operational or still in planning and development phase, no citable material was available at the time of printing. A list of resources used to develop this information is provided in the Citations section of this Guide. The most updated account of current, completed, and future payloads can be found on the Earth Science and Remote Sensing Missions on ISS site: https://eol.jsc.nasa.gov/esrs/ISS_Remote_Sensing_Systems/.

Current Payloads

Internal Payloads

Image captures multiple wildfires burning simultaneously across the state of California on August 3, 2018. Fires burned through 450,000 acres and damaged/destroyed up to 2,000 structures (ISS056E12669).

Crew Earth Observations (CEO), Launched November 2000
Historically, the Crew Earth Observations (CEO) program has been a major source

of data provided by the ISS. While still an important part of the ISS, the additional remote sensing instruments currently aboard, as well as those planned for the future, will further enhance the opportunities for quantitative Earth remote-sensing research and applications from the ISS. Over the past decade, CEO has increasingly emphasized disaster response in support of the International Charter, Space and Major Disasters (https://disasterscharter.org/home; also known as the International Disaster Charter, or IDC), and the agency's Earth Science Disasters Program. Additional capabilities of CEO include high-resolution nighttime imagery of urban and suburban areas, and time-lapse sequence imagery of atmospheric phenomena such as airglow and aurora.

Nighttime view of Bangkok, Thailand, from the International Space Station in December 2017. The Andaman Sea and Gulf of Thailand are illuminated by hundreds of green lights used by fishermen to attract plankton and fish (ISS053E451778).

Nighttime images of cities are striking and useful for urban climate and light pollution studies, disaster response (blackouts), modeling urban land use, and population density. ISS photographs of cities at night are valuable because they provide greater spatial resolution than other publically available orbital sources of night light data. As such, city light imagery from the ISS complements coarser spatial resolution data from other sensors.

The CEO program involves crew members using professional-grade commercial off-the-shelf (COTS) handheld digital cameras with a suite of lenses (from wide angle to a 1600-mm lens equivalent) to take Earth observation photographs that support research and applications in a wide variety of Earth Science disciplines, including disaster response. Scientists on the ground train the crew in areas of basic Earth system science and provide the crew a daily list of targets focused on dynamic events (such as IDC activations), educational outreach, and approved science targets. Crew members take these photographs on a "task-listed" basis, meaning that collection of imagery is at the crew's discretion based on other scheduled priorities during their work day.

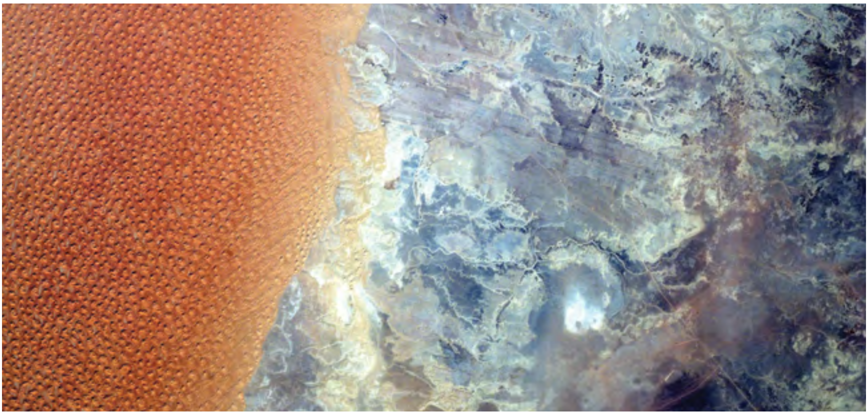
These digital photographs are downlinked, their location identified and both images and meta-data are assimilated into a public database, the Gateway to Astronaut Photography of Earth (https://eol.jsc.nasa.gov). The website also features searchable access to all the photographs and a public cataloging facility.

The images can be used as educational and research tools, as well as historical records of global environmental changes, geological and weather events, and the growth and change of human-made features such as cities. Analyses using CEO data have been published in scientific journals in a wide variety of disciplines. While imagery can be collected from any available window on space station, they are currently conducted primarily from the windows in the Russian Zvezda service module and the ISS Cupola.

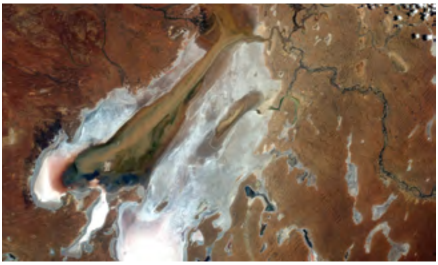
Through their photography of the Earth, ISS crew members build on the time series of imagery started with the first human spaceflights, ensuring that this continuous record of Earth remains unbroken.

Sally Ride EarthKAM, Launched March 2001
Earth Knowledge Acquired by Middle school students (EarthKAM) is a NASA educational outreach program that enables students, teachers, and the public to learn about Earth from the unique perspective of space.

Initiated in 1995 by Dr. Sally Ride, America's first woman in space, EarthKAM (formerly known as KidSat) involves middle school students around the world requesting images of specific locations on Earth (Hurwicz et al. 2002). The program collection can be found in the Sally Ride EarthKAM archive: http://images.earthkam.org/main.php.



Taken through a window on the International Space Station on October 31, 2017, this EarthKAM photo shows the boundary between a major dune field and dark hills along the border between Algeria and Libya. These landscapes are among the driest parts of the Sahara Desert (EarthKAM photo: CCFID_152293_2017304121045).



Acquired on Feb. 14, 2017, with a Nikon D2Xs digital camera using a 50 mm lens, this photograph shows Australia's largest inland lake, Lake Eyre. Usually dry, Lake Eyre underwent a change in 2017. Instead of evaporating before reaching the lake or being absorbed by dune sand, the abundance of rain in late 2016 reached Lake Eyre after a delay of months. The lake is more formally known as Kati Thanda–Lake Eyre (EarthKAM photo: CCFID_126465_2017038014745).

Upon request from middle school students, this EarthKAM photo was taken on April 13, 2016, capturing dense clusters of agricultural fields radiating across a large alluvial fan in Afghanistan. Alluvial fans are fan- or cone-shaped deposits of sediment crossed and built up by streams. People and their crops use the majority of the water coming out of the canyon, resulting in little water flowing off the fan (EarthKAM photo: CCFID_103323_2016104095502).

External Payloads

High Definition Television Camera System for JEM Exposed Facility 2 (HDTV-EF2), Launched December 2016

The HDTV-EF2 is the successor system to the earlier HDTV-EF (also developed by JAXA) that operated from 2012 to 2015. The system includes two Commercial Off the Shelf (COTS) video cameras, one of which is capable of 4K image resolution. The HDTV-EF2 collects imagery of the Earth and spacecraft for public release in support of scientific and educational purposes. The system also acquires data for disaster response through JAXA involvement in the Sentinel Asia program (Okazaki and Mano, 2018).

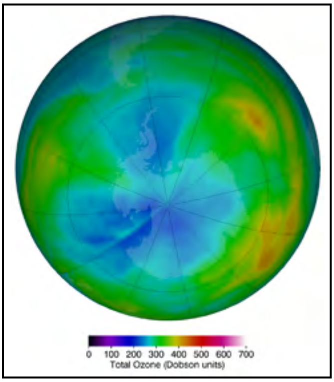
Space Test Program-H5-Lightning Imaging Sensor (STP-H5-LIS), Launched February 2017
Based on observations from previous space-borne lightning detectors on free flying satellites, lightning strikes somewhere on the Earth 45 times every second. Launched in early 2017, the International Space Station LIS continues the legacy of these lightning observations, using a sensor similar to the Tropical Rainfall Measuring Mission (TRMM) LIS to determine the amount, rate, and energy of lightning around the world.

The sensor can locate ground and cloud lightning strikes on a global scale while providing researchers with real-time data to analyze. The lightning detector is a compact combination of optical and electronic elements capable of locating and detecting lightning within individual storms. The ISS-LIS contains a staring imager which is optimized to locate and detect lightning with a storm-scale resolution of 4 km at nadir (directly below the instrument), increasing to 8 km at limb (at edge of measurement region), over a large region of about 550 km of the Earth's surface. The Field-of-View (FOV) is sufficient to observe a point on the Earth or a cloud for about 90 seconds with a 2 millisecond sampling frequency, adequate timing to estimate the lightning flash rate of many storms.

Recorded data can provide an improved understanding of the nature of lightning and its connection to the weather, serving as a foundation for understanding atmospheric chemistry and physics, predicting weather and climate, and advancing aircraft and spacecraft safety (Peterson, et al. 2017).

Stratospheric Aerosol and Gas Experiment (SAGE-III), Launched February 2017
More than 25 years ago, scientists realized that the layer of colorless gas high above the Earth's surface that absorbs and protects living things from harmful ultraviolet-B radiation is thinning. SAGE-III, a part of the SAGE sensor family responsible for obtaining accurate measurements of ozone loss in the Earth's atmosphere and measuring onset ozone recovery, continues the legacy of studying the ozone layer from the International Space Station.

The data from the original SAGE led to the discovery of a hole in the stratospheric



This false-color map illustrates the total ozone over the Antarctic pole in July 2019. The blue and purple colors show the least ozone, and the yellows and reds areas are where there is more ozone.

ozone layer stretching across Antarctica. This discovery led to the drafting of the Montreal Protocol, an international agreement to protect the ozone layer from oxygen-depleting substances. Since ratification of the Protocol in 1988, the ozone layer has been in recovery, and monitoring efforts continue with SAGE-III.

Total Solar Irradiance (TSI) Spectral Solar Irradiance (SSI) (TSIS-1), Launched December 2017
Solar radiation is the Earth's primary source of energy, affecting the planet's surface structure and atmospheric conditions. It powers Earth's complex and dynamic systems — interactions among the land, oceans, and atmosphere — that maintain the environments that humanity and other species inhabit. When solar radiation output from the sun is in balance with the infrared radiation the Earth emits, the climate experiences fewer fluctuations than when these energies are imbalanced. Having the ability to monitor this energy is important to climate science.

The TSIS-1 payload measures the total solar irradiance (TSI), which is all of the radiant energy coming from the Sun. The solar spectral irradiance (SSI) is also measured to determine how that energy is distributed among different wavelengths and where in the atmosphere that energy is absorbed. This data is crucial to building a better understanding of solar activity and how the Earth's atmosphere responds to changes in solar output. The TSIS-1 continues over 40 years of solar data collection and is used to create models and simulations that can potentially enhance weather predictions, including solar winds and geomagnetic storms. These predictions can also help protect humans and satellites in space while enhancing radio transmissions on the ground. Continuously monitoring solar radiation data is also important to climate change models.

Atmosphere-Space Interactions Monitor (ASIM), Launched April 2018
The Atmosphere-Space Interactions Monitor (ASIM) is a climate observatory on the International Space Station that monitors transient luminous events (e.g., sprites, blue jets, and ELVES) and terrestrial gammas ray flashes from the external payload platform of European Space Agency (ESA) Columbus External payload

Facility. This payload provides a large, comprehensive survey of these transient luminous events and terrestrial gammas ray flashes in a region of the atmosphere within and above severe thunderstorms. The results from ASIM can improve current atmospheric models, including predictions related to climatology, and may improve understanding of the physics of these events and how they relate to lightning.

The ASIM contains the Miniature Multispectral Imaging Array (MMIA) and the Data Handling and Power Unit (DHPU). The MMIA is comprised of three separate modules, each housing two video cameras and two photometers (an instrument used for measuring the intensity of light). Two out of three modules are positioned in the ram direction and the other faces the nadir direction. The DHPU establishes and maintains all electrical interfaces between ASIM and the ISS. It also administers a data link connection and a serial line for updates and patches to its firmware (Østgaard, et al. 2019).

NanoRacks-ISS-Hyperspectral Earth Imaging System Trial (NanoRacks-ISS-HEIST), Launched February 2018
The NanoRacks-ISS-Hyperspectral Earth Imaging System Trial project implements pre-existing technology to produce, launch, and operate one of the first orbital hyperspectral sensor systems for commercial Earth observation. Smaller and less expensive than preceding sensors, the NanoRacks-ISS-HEIST serves as a testbed for commercial off-the-shelf components, as well as flight and camera control software and processing and storage capabilities.

Current space-based Earth observation platforms rely on panchromatic or multispectral sensors, which are limited to detecting only a handful of spectral bands. This payload's hyperspectral sensor collects hundreds of narrow spectral bands, resulting in extremely high spectral resolution. This higher precision also allows for monitoring of specific chemical changes and identification of material composition.

Once operational, the NanoRacks-ISS-HEIST can provide a space-based visible/near Infrared (VNIR) hyperspectral sensing platform that can replace the decommissioned Hyperspectral Imaging Coastal Observatory (HICO).

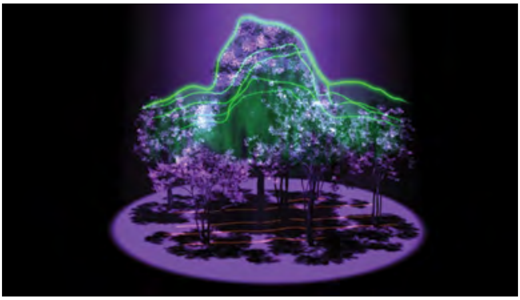
DLR Earth Sensing Imaging Spectrometer (DESIS), Launched June 2018
Developed by the German Aerospace Center (DLR) and the U.S. company Teledyne Brown Engineering (TBE), the DESIS is an environmental and resource monitoring system. DESIS enhances the use of space-based hyperspectral (from the visual to near infrared spectrum) imaging capabilities for Earth remote sensing while also providing high value hyperspectral imagery for Teledyne Brown Engineering for

commercial purposes. The scientific and commercial benefits include (as examples) better management of agricultural and forest ecosystems, urban development, natural and environmental disaster assessment, and humanitarian response (Eckardt, et al. 2015).

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), Launched June 2018
Plants regulate their temperatures by releasing water through tiny pores on their leaves called stomata. If they have sufficient water, they can maintain their temperature; but if there is insufficient water, their temperatures rise. This increase in temperature can be measured with a sensor in space.

Installed on the Japanese Experiment Module-Exposed Facility (JEM-EF), the ECOSTRESS provides the first-ever high spatiotemporal (space-time) resolution thermal infrared measurements of the surface of the Earth from the International Space Station (ISS). These measurements allow scientists to answer questions related to changes in water availability, how changes in daytime vegetation water stress may affect the global carbon cycle, and how agricultural vulnerability may be reduced through advanced monitoring of water use and improved drought estimation.

Global Ecosystem Dynamics Investigation (GEDI), Launched October 2018



"Lidar" is an active remote-sensing technology that uses pulses of laser light to create 3-dimensional representations of the target. These 3-dimensional architectures, as depicted in this concept art, provide much-needed clarification on how much carbon trees contain. Results from the data can assist in understanding the consequences of deforestation and preparing effective regrowth operations.

Developed at NASA Goddard Space Flight Center, the Global Ecosystem Dynamics Investigation (GEDI) is a full-waveform lidar instrument that makes detailed measurements of the 3D structure of the Earth's surface.

GEDI is the first spaceborne laser instrument to measure the structure of Earth's forests in high resolution and three dimensions. GEDI's unprecedented precision advances our ability to understand the impact of carbon and water cycling processes, biodiversity, and habitat as global temperatures increase.

The surface structure information collected by GEDI also improves weather forecasting, monitoring of changes to glacier volume and snowpack, and management of forest resources (Patterson, et al. 2019).

Orbiting Carbon Observatory-3 (OCO-3), Launched May 2019

Artist's rendition of OCO-3 measuring the intensity of the sunlight reflected from presence of CO_2 in a column of air.

The Orbiting Carbon Observatory–3 is a complete stand-alone payload built using the spare OCO-2 flight instrument, with additional elements added to accommodate installation and operation on the International Space Station (ISS). It will investigate important questions about the distribution of carbon dioxide on Earth as it relates to growing urban populations and changing patterns of fossil fuel combustion. OCO-3 will explore, for the first time, daily variations in the release and uptake of carbon dioxide by plants and trees in the major tropical rain forests of South America, Africa, and South-East Asia, the largest stores of above ground carbon on our planet.

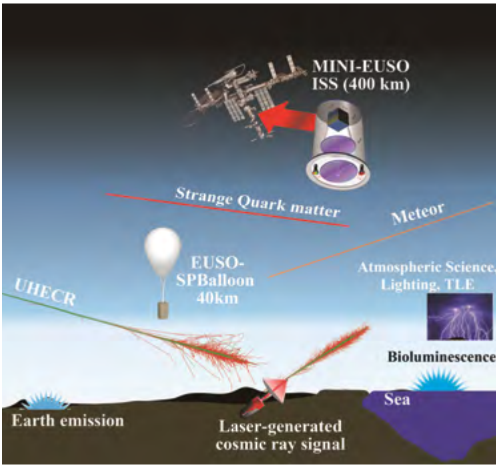
The OCO-3 instrument consists of three high-resolution grating spectrometers that collect space-based measurements of atmospheric carbon dioxide (CO_2) with the precision, resolution, and coverage needed to assess the spatial and temporal variability of CO_2 over an annual cycle. After launch and docking with the space station, the OCO-3 instrument will be installed on the ISS Japanese Experiment Module – Exposed Facility (JEM-EF), where it will be operating for the duration of the mission. The instrument will acquire data in three different measurement modes. In Nadir Mode the instrument views the ground directly below the space station.

In Glint Mode, the instrument tracks near the location where sunlight is directly reflected on the Earth's surface. Glint Mode enhances the instrument's ability to acquire highly accurate measurements, particularly over the ocean. In Target Mode, the instrument views a specified surface target continuously as the ISS passes overhead. Target Mode provides the capability to collect a large number of measurements over sites where ground-based and airborne instruments also measure atmospheric CO_2. The OCO-3 science team will compare Target Mode measurements with those acquired by ground-based and airborne instruments to validate OCO-3 mission data. The Observatory has a planned operational life of three years (Stavros, et al. 2017).

Planned Future Payloads

Internal Payloads

Mini Extreme Universe Space Observatory (Mini-EUSO), Launched 2019



From the vantage point of the Russian Service Module, the mini-EUSO will be recording atmospheric components (e.g., ultraviolet rays) and events such as meteors and cosmic ray showers. This representation lists several other subjects under observation.

The Mini Extreme Universe Space Observatory is an ultraviolet telescope set to serve as a pathfinder for future Ultra-High-Energy Cosmic Ray (UHECR) missions and to map UV light emissions from Earth. The mini-EUSO will launch and be performing experiments in the Russian Zvezda Service Module of the International Space Station in 2019.

Comprised of a wide field of view for increasing light collection, the mini-EUSO is designed to study atmospheric phenomena, such as Transient Luminous Events (TLEs), meteors and meteoroids, the search for Strange Quark Matter (SQM), and the detection of some cosmic ray showers.

The mini-EUSO has been approved by the Russian State Space Corporation ROSCOSMOS and included in the "Long Term Program for Scientific Experiments and Applied Research planned for the Russian segment on ISS," under the name UV Atmosphere. This project has also been approved by the Italian Space Agency (ASI) (Capel, et al. 2018).

External Payloads

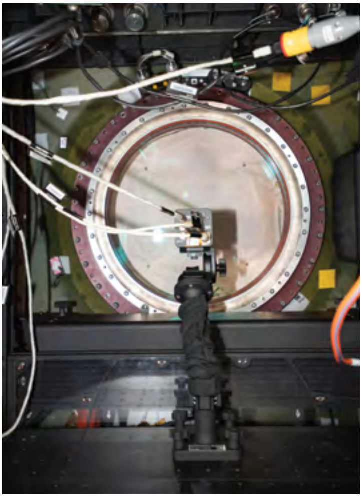
Climate Absolute Radiance and Refractivity Observatory Pathfinder (CLARREO CPF), Launch Date 2023
The Climate Absolute Radiance and Refractivity Observatory Pathfinder (CPF) will observe and measure the complete spectrum of radiation from the Sun reflected by the Earth, providing better insight into how the planet's cloud radiative feedback impacts climate. The CPF will take direct measurements of the Earth's thermal infrared spectrum (including the far-infrared), the complete spectrum of solar radiation reflected by the Earth and its atmosphere, and radio occultation from which accurate temperature profiles are derived. These measurements will provide information on critical climate parameters such as forcing mechanisms, responses, and feedbacks associated with the vertical distribution of atmospheric temperature and water vapor, reflected and emitted radiative fluxes, cloud properties, and surface variables including albedo, temperature, and emissivity.

Hyperspectral Imager Suite (HISUI), Launch Date 2019
The Hyperspectral Imager Suite (HISUI) is a spaceborne hyperspectral Earth imaging system being developed by the Japanese Ministry of Economy, Trade, and Industry (METI). The imager will record information in the visible through shortwave infrared wavelengths over 185 discrete bands, with a planned spatial resolution of 20 m x 30 m. This payload is scheduled to launch and operate onboard the International Space Station (ISS) for a three-year investigation in 2019 to support a variety of research-oriented and commercial Earth observations (Matsunaga, et al. 2017).

Completed Payloads

Internal Payloads

Meteor Composition Determination (METEOR), March 2016 - February 2019
Meteor spectra are commonly recorded by ground or aircraft instruments and compared to synthetic spectra to determine elemental abundances and temperatures. However, meteors are relatively rare and are difficult to observe from the ground because of interference from the Earth's atmosphere. The Meteor Composition Determination (METEOR) mission made the first space-based observations of the chemical composition of meteors entering Earth's atmosphere. METEOR provided continuous high-resolution video and images of meteor interactions with the Earth's atmosphere without limitations of ozone absorption.



METEOR, shown in the image above, involves mounting a camera programmed to record predictable showers and unpredicted Earth-meteor interactions, in a mock-up camera in the WORF simulator at the Johnson Space Center.

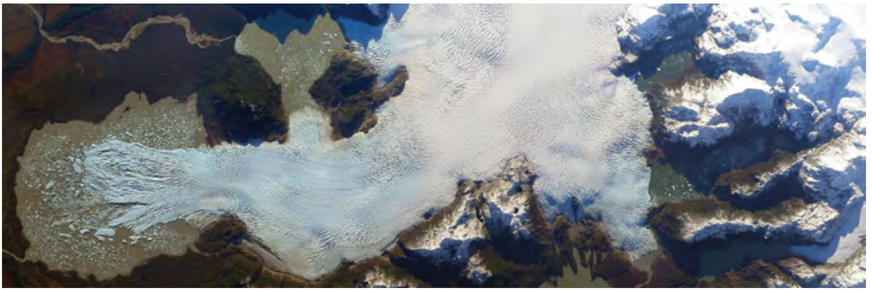
METEOR's mission objective involved flying a visible spectroscopy instrument to the International Space Station (ISS) to observe meteors in Earth orbit. Southwest Research Institute (SwRI) served as the U.S. host and conducted this experiment on behalf of Chiba Institute of Technology, based in Japan.

The METEOR investigation data provided the first measurement of meteor flux and allows for future monitoring of carbon-based compounds in meteors entering Earth's atmosphere. Analyzing meteor elemental compositions is crucial to our understanding of how planets like our own develop.

ISS SERVIR Environmental Research and Visualization System (ISERV) Pathfinder, May 2012-September 2015
The ISS SERVIR Environmental Research and Visualization System (ISERV) Pathfinder was a fully automated image data acquisition system that flew aboard the International Space Station (ISS). It was deployed in the Window Observational Research Facility (WORF) rack within the Destiny module.

Comprised of a commercial off-the-shelf (COTS) camera, telescope and pointing system that were commanded remotely from Earth by researchers at NASA's Marshall Space Flight Center in Huntsville, Alabama, ISERV captured three images per second that covered approximately 19 km x 11 km area each. Although the purpose of the ISERV was to improve automatic image capturing and data transfer, the images taken in the experiment also aided environmental scientists, disaster responders and other Earth-based users.

The ISERV was a resource for environmental decision-making and the monitoring of natural disasters and events that impacted the Earth's surface. During its runtime, ISERV supported the goals of NASA's SERVIR (Spanish for "to serve") project.



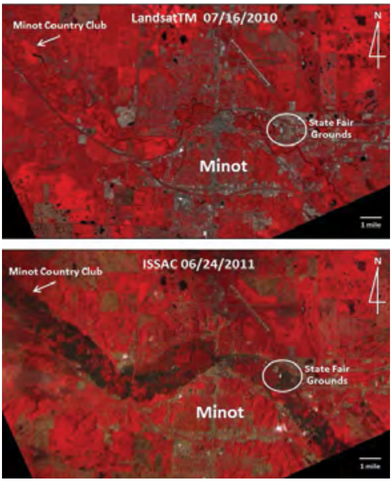
On June 2, 2014, ISERV snapped eight images of San Quintín Glacier, a landmass situated within Laguna San Rafael National Park that drains west toward the Pacific Ocean. In the photo, hundreds of icebergs surround the glacier's end, while a stream flows west toward the Golfo de Peñas on the Pacific Ocean. The photo reveals the glacier experiencing massive shedding and rapid retreating. NASA image from ISERV Pathfinder, SERVIR program.

SERVIR, a joint venture between NASA and the U.S. Agency for International Development in Washington, provides a conglomerate system of data, models, and information products to support and inform the environmental decision-making process in various regions. Through its various hubs around the world, SERVIR provides decision support mechanisms in a variety of areas such as drought and flood monitoring, landslide probability mapping, disease incidence mapping, and air quality and environmental condition monitoring.

Remotely sensed data acquired by orbital sensor systems such as ISERV have become vital tools to identify the extent of damage from a natural disaster while also providing near-real-time mapping support to response efforts on the ground and for humanitarian aid efforts (Kansakar, et al. 2016).

International Space Station Agricultural Camera (ISSAC),
January 2011-January 2013
The International Space Station Agricultural Camera (ISSAC) was active aboard the ISS from January 2011 to January 2013. It was a multi-spectral camera installed in the ISS as a sub-rack payload of the WORF. A single 150-mm lens and optical beam splitter supplied light to three digital framing cameras, each with its own filter: green, red (630-690 nm) and near infrared (780- 890 nm).

Normal payload operations were commanded via ground uplink. Commands were stored in an on-board command queue and executed based on system time supplied by the ISS. Imagery collected was downlinked via the medium-rate payload LAN. The onboard command queue capability allowed autonomous 24-hour operations, enabling routine worldwide target accessibility.



Comparison of Minot, N.D., and Souris River Valley during normal river flow conditions (top image, Landsat Thematic Mapper data) and during flood conditions (bottom image, ISSAC data). Both images have been processed to highlight actively photosynthesizing vegetation in red. Urban areas appear as gray-brown.

The red and near-infrared bands within ISSAC were similar to those used on satellite-based broadband, multi-spectral systems used for studying vegetation. Agricultural efficiency and competitiveness can be enhanced through the practical application of data products that are derived from reflectance measurements taken in these spectral regions. ISSAC was focused on studying aspects of agricultural efficiency that are of particular importance to the northern Great Plains. These same capabilities of ISSAC were applicable worldwide to scientific study of any areas undergoing rapid ecosystem change. Targets ranged from natural systems such as glacier melt or plant phenological transitions such as spring green-up and fall senescence to human impact such as deforestation and urbanization (Olsen, et al. 2011).

The sensor also contributed to the ISS capability to collect data for humanitarian aid to areas struck by natural disasters through the International Charter, Space and Major Disasters (IDC) (https://disasterscharter.org/home). The ISSAC collected data for several IDC activations, including fires in northern Africa, flooding in Pakistan, and the aftermath of Hurricane Sandy in the U.S.

External Payloads

High Definition Earth-Viewing System (HDEV), March 2014 – August 2019

On the left is a picture of the HDEV system attached to the European Space Agency Columbus External Payload Facility. On the right is a snapshot of footage from the HDEV, capturing a view of Tropical Storm Leslie. The storm struck the Iberian Peninsula and the East Cost of the United States in September and October 2018.

The High Definition Earth Viewing (HDEV) investigation used four commercially available HD cameras mounted on the Columbus External Facility to live stream video of Earth for online viewing. The cameras were enclosed in a temperature-specific housing and were exposed to the harsh radiation of space. While the HDEV collected beautiful images of the Earth from the ISS, the primary purpose of the experiment was an engineering one: monitoring the rate at which HD video camera image quality degraded when exposed to the space environment (mainly from cosmic ray damage) and verifying the effectiveness of the design of the HDEV housing for thermal control.

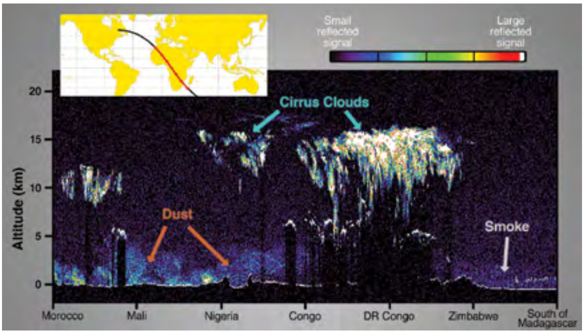
The HDEV cameras were a fixed payload system with no zoom, pan or tilt mechanisms. The four fixed cameras were targeted for imagery of the Earth's surface as seen from the ISS (i.e., one camera pointing forward into the station's velocity vector, two cameras pointing aft [wake], and the remaining camera pointing nadir). The video imagery was encoded into an Ethernet-compatible format for transmission to the ground and further distribution. In this format, the video could be viewed from any computer connected to the internet.

The HDEV operated one camera at a time. The forward-facing camera was powered first, followed by the nadir and each aft-facing camera, such that the HDEV video would "follow" a location on the Earth as the ISS passed overhead. This auto-cycle mode of the HDEV did not require input from ground operators.

Alternately, the HDEV video could be commanded by ground controllers when desired. Ground operators had the choice to change the cycle of the images noted in the auto-cycle mode, changing either which cameras were powered or the length of time they were powered. If desired, ground controllers could command a single camera to remain powered on and for no auto-cycle to take place (Schultz, et al. 2017). Footage was streamed live from the HDEV cameras and could be viewed by the public via a website.

The "Columbus Eye" project, developed by the University of Bonn and sponsored by the German Aerospace Center (DLR) Space Administration, involved receiving, archiving, and preparing imagery from the HDEV investigation for educational purposes. Students could observe Earth from an astronaut's perspective while applying remote sensing analysis tools using the High Definition Earth Viewing (HDEV) camera. The Columbus Eye video archive and HDEV project highlights are freely available at the Columbus Eye portal www.columbuseye.uni-bonn.de.

Cloud-Aerosol Transport System (CATS), January 2015-October 2017



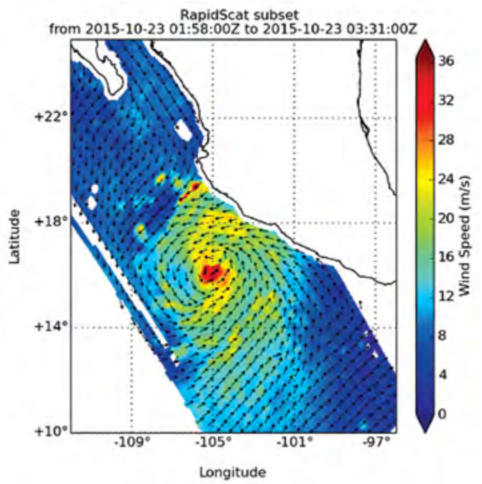
Above is a cross-section of the atmosphere over Africa recorded by the Cloud-Aerosol Transport System (CATS). Cirrus Clouds, dust, smoke from fires, and topography were tracked diagonally from Morocco to South of Madagascar.

The Cloud-Aerosol Transport System (CATS), launched and mounted on the Japanese Experiment Module-Exposed Facility (JEM-EF) in 2015, was a high spectral resolution LiDAR (Light Detection and Ranging) that used a laser to gather profile measurements of atmospheric aerosols and clouds from the International Space Station. Aerosols are tiny particles in the atmosphere and include dust from deserts, sea salt, smoke from wildfires, sulfurous particles from volcanic eruptions, and pollution. Clouds and aerosols play an important role in the planet's climate system and air quality.

Similar instruments on existing satellites such as the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) can detect aerosol plumes but cannot determine their composition. CATS better detected aerosol particle properties, allowing researchers to better determine plume components and improve studies of aerosol transport and cloud motion. The results provided direct evidence that space-based LiDAR detection at 1064 nm is more representative of true above-cloud aerosols compared to 532 nm (Yorks, et al. 2016).

International Space Station-RapidScat (ISS-RapidScat), September 2014-November 2016

Launched in September 2014, the International Space Station-RapidScat (ISS-RapidScat) was a cost-effective replacement for NASA's QuikScat Earth satellite (1999-2009), which provided valuable data on ocean winds and revolutionized environmental predictions and weather forecasting. After QuikScat stopped collecting data, NASA's Jet Propulsion Laboratory and the agency's Station program designed a replacement that used the framework of the International Space Station and reused hardware originally built for the QuikScat: the ISS-RapidScat.



On October 23, 2015, NASA's ISS-RapidScat passed over Hurricane Patricia, a Category 5 tropical cyclone that struck Texas, Mexico, and Central America. RapidScat measured ocean surface, wind speed, mapping hurricane movements and enabling weather forecasters and other researchers to predict how these storms evolve over time. Image credit: NASA/JPL-Caltech

The RapidScat instrument monitored ocean winds from the unique vantage point of the space station in real-time. Tracking ocean winds helps in determining regional weather patterns: information crucial to effective weather forecasting. Its measurements of wind speed and direction over the ocean surface were used by agencies nationwide for weather and marine forecasting as well as for monitoring hurricanes and tropical cyclones.

The first of its kind on Station, ISS-RapidScat kept a close eye on ocean winds in remote areas, helping researchers become more knowledgeable of fundamental weather and climate processes, such as how tropical weather systems manifest and evolve.

Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES), March 2009-September 2014

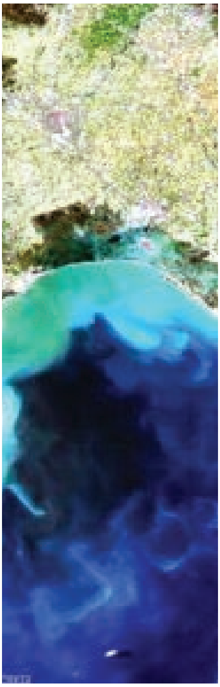
The ozone layer is the Earth's spacesuit, protecting the ecosystem and the human population by absorbing the Sun's most harmful ultraviolet rays. However, manmade pollutants such as Freon gas have been destroying the ozone layer. Freon, which has been used as refrigerants for refrigerators and air conditioners, dissolves in the stratosphere and turns into ozone-destructive substances.

Measuring the atmospheric ozone and its chemical composition is crucial for understanding the ozone layer depletion. The Superconducting Submillimeter-Wave Limb Emission Sounder (SMILES) was a sensitive submillimeter sounder designed to globally map stratospheric gases. During its investigation, SMILES provided scientists with the opportunity to analyze atmospheric phenomena in unprecedented detail and served as a valuable tool to prove the accuracy of climate models.

Comparing SMILES data with other sources showed an agreement of stratospheric ozone in the mesosphere and at high altitudes of 45 miles. However, SMILES data quality was found to be poor in low altitudes.

SMILES data also showed ozone loss at various altitudes inside the polar vortex for the Arctic winter. Measuring chemicals, such as chlorine monoxide radical (ClO), hydroxyl radical (HO_2), hydrochloric acid (HCl) and Hypochlorous acid (HOCl) in the middle atmospheric, SMILES gave the first global observations of the diurnal variations of hypochlorous acid in the upper atmosphere (Kikuchi, et al. 2010).

Hyperspectral Imager for the Coastal Ocean (HICO), March 2009–Fall 2014



This image of the Acqua Alta Oceanographic Tower in Italy was taken by the HICO on March 7, 2014. Data from HICO is analyzed to find bathymetry and water optical properties.

The Hyperspectral Imager for the Coastal Ocean (HICO) was an imaging spectrometer based on the Portable Hyperspectral Imager for Low-Light Spectroscopy (PHILLS) airborne imaging spectrometers (Corson, et al. 2008). It was launched to the ISS in 2009, mounted on the Japanese Experiment Module-Exposed Facility (JEM-EF) for operations, and integrated with the Remote Atmosphere and Ionospheric Detection Systems (RAIDS) to form the HICO and RAIDS Experiment Payload (HREP).

The RAIDS device measured the thermosphere, which creates atmospheric drag on space vehicles and satellites and is affected by solar activity. RAIDS also studied the ionosphere, which has a strong influence on radio, radar, and satellite navigation signals. Imagery captured during HREP's five-year mission provided new data about how sunlight, cloud cover and different viewing angles can affect images taken in low-Earth orbit.

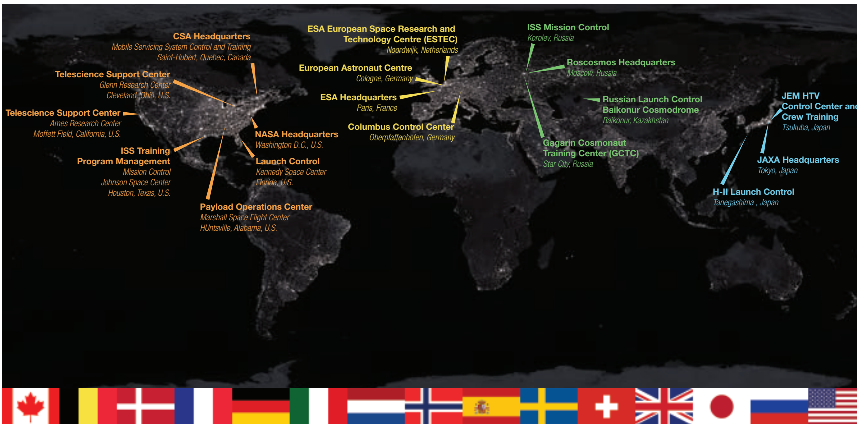
HICO was the first spaceborne imaging spectrometer designed to sample the coastal ocean. HICO sampled selected regions at approximately 90 m Ground Sample Distance (GSD) with full spectral coverage (400 to 900 nm sampled at 5.7 nm) and signal-to-noise ratio sufficiently high to resolve the complexity of the coastal ocean. Scientists from U.S. agencies, U.S. commercial interests, ISS International Partners, and academia, both U.S. and international, expressed interest in receiving and using HICO data to develop new algorithms and to study coastal ocean dynamics.

The primary mission of HICO as an ISS sensor was to provide hyperspectral remote-sensing data to U.S. users to benefit the nation, expand and extend the applications of hyperspectral data from orbit, and meet NASA science goals from the Earth Science Decadal Survey. During its five-year investigation, HICO demonstrated the capability for retrieval of coastal ocean depth, chlorophyll content, sea floor composition and water visibility, which are vital for rapid and safe maneuvers in coastal environments (Huemmrich, et al. 2017).

Future Earth-Observing Sensors

The ISS U.S. National Laboratory, formerly known as the Center for the Advancement of Science in Space (CASIS), in conjunction with NASA, continues to solicit new sensors that efficiently take advantage of the station as a remote-sensing platform. Technologies for multispectral and hyperspectral sensors as well as active radar and LiDAR systems continue to advance, providing both instrument developers and end-users with new opportunities in research and applications of remotely sensed data. In addition, international partners such as Japan Aerospace Exploration Agency (JAXA), European Space Agency (ESA) and ROSCOSMOS are planning to launch new sensors and perform experiments in the coming years.

Operational Support



The overall management and control of the International Space Station is spread over four continents—North America, Europe, Russia, and Asia. Each international center communicates and works together 24/7 to keep the orbiting laboratory running, the crew safe, and the science ongoing.

The ISS and payload operations are supported by different mission control centers (MCCs). The prime operational mission control center is split between MCC in Houston, Texas, at NASA's Johnson Space Center (JSC), and the Russian Control Center near Moscow, Russia. Payload support is provided primarily through the Payload Operations and Integration Center (POIC) at NASA's Marshall Space Flight Center (MSFC) in Huntsville, AL, with additional payload support provided by JSC and at NASA's Kennedy Space Center. Additionally, international partners maintain control centers in Germany (the Columbus Control center near Oberpfaffenhofen, Germany); the Tskuba Space Center (TKSU) in Japan; the Canadian Space Agency Mission Control Center (CSA-MCC), in Longueuil, Quebec, Canada; and the CSA-Payloads Telescience Operations Center (PTOC), in St. Hubert, Quebec, Canada.

The MSFC POIC coordinates all U.S. scientific and commercial experiments on the station, synchronizes payload activities of international partners and directs communications between researchers around the world and their onboard experiments. The Payload Operations Center integrates research requirements, planning science missions and ensuring that they are safely executed. It integrates crew and ground team training and research mission timelines. It also manages use of space station payload resources, handles science communications with the crew, and manages commanding and data transmissions to and from the orbiting research center.

The Payload Operations Center processes hundreds of payload commands per day. It also continuously monitors the health and status of scientific instruments deployed on the space station. Since 2001, thousands of investigations have been completed. Following space station assembly completion in 2011, more crew time has been devoted to science activities. The POIC is staffed around the clock by three shifts of flight controllers to help the crew as they conduct more and more science investigations.

In addition, staff and facilities at the JSC help support Earth Observation payloads through the Earth Science and Remote Sensing Unit (ESRS) within NASA JSC's Astromaterials Research and Exploration Science Division in the Exploration Integration Science Directorate. The purpose of the Astromaterials Division is to combine advancements in science and technology to push human space exploration forward, to apply planetary research, and to develop mitigation methods to establish successful space travel. The ESRS Unit supports space-based remote sensing from the ISS and participates in disaster response initiatives.

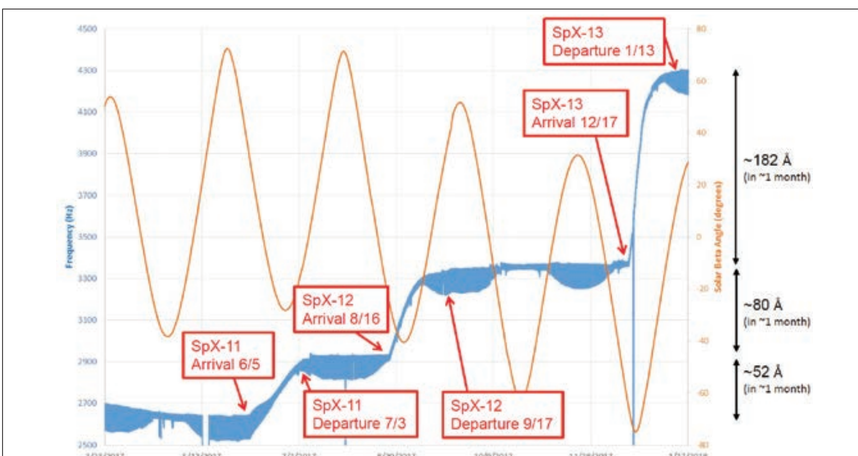
The ESRS includes the CEO group responsible for generating image target lists for the ISS crew, reviewing all imagery acquired, cataloging the processed imagery, and providing all imagery to the public via the Gateway to Astronaut Photography of Earth website: https://eol.jsc.nasa.gov/. In addition, the CEO staff provides crew training, produces varied proposals for scientific research, and serves as an important conduit for public outreach for both the ISS Program and NASA in general. The ESRS also coordinates disaster response from the ISS through the NASA Earth Science Disasters Program (https://disasters.nasa.gov) in cooperation with the United States Geological Survey (USGS) and serves as a general remote-sensing resource for additional Earth science payloads, both present and future, within the ISS Program.

Launch services for the ISS are supplied by several sources, including Space X (Falcon 9 and Dragon), Northrop Grumman (Antares and Cygnus), JAXA (HTV), and ROSCOSMOS (Progress and Soyuz). In collaboration with NASA's Commercial Crew Program, aircraft manufacturing company Boeing is developing their Crew Space Transportation (CST)-100 Starliner spacecraft intended for low-Earth orbit (LEO) missions.

Lessons Learned

As an orbital, Earth-viewing platform, success or failure in collecting data is dependent on several factors both internal and external to the ISS. Cloud cover can frequently preclude useful data collection by optical sensors over some parts of the Earth; likewise the ISS orbit and seasonal variations can limit the availability of sufficient illumination of ground targets. For human-tended systems, limiting constraints involve not only the environmental viewing constraints, but also limitations imposed by the crew's work schedule, including the time required for payload installation and trade-outs. Data downlink capacity also must be carefully evaluated when planning to use instruments or measurements with high data volume observations and time- sensitive data collection.

Precision targeting from the WORF was an issue for ISSAC because of its inability to access the full temporal resolution ISS position feed (1 Hz). There were similar issues with ISERV and HICO regarding the focus of their telescopes and cameras, as well as data downlinking capabilities and automated geolocation of imagery. These are potential issues payload designers should take into consideration during the development phase of their instruments. The ISS operational and design community actively engages with payload developers to find solutions for these and other platform-specific issues.



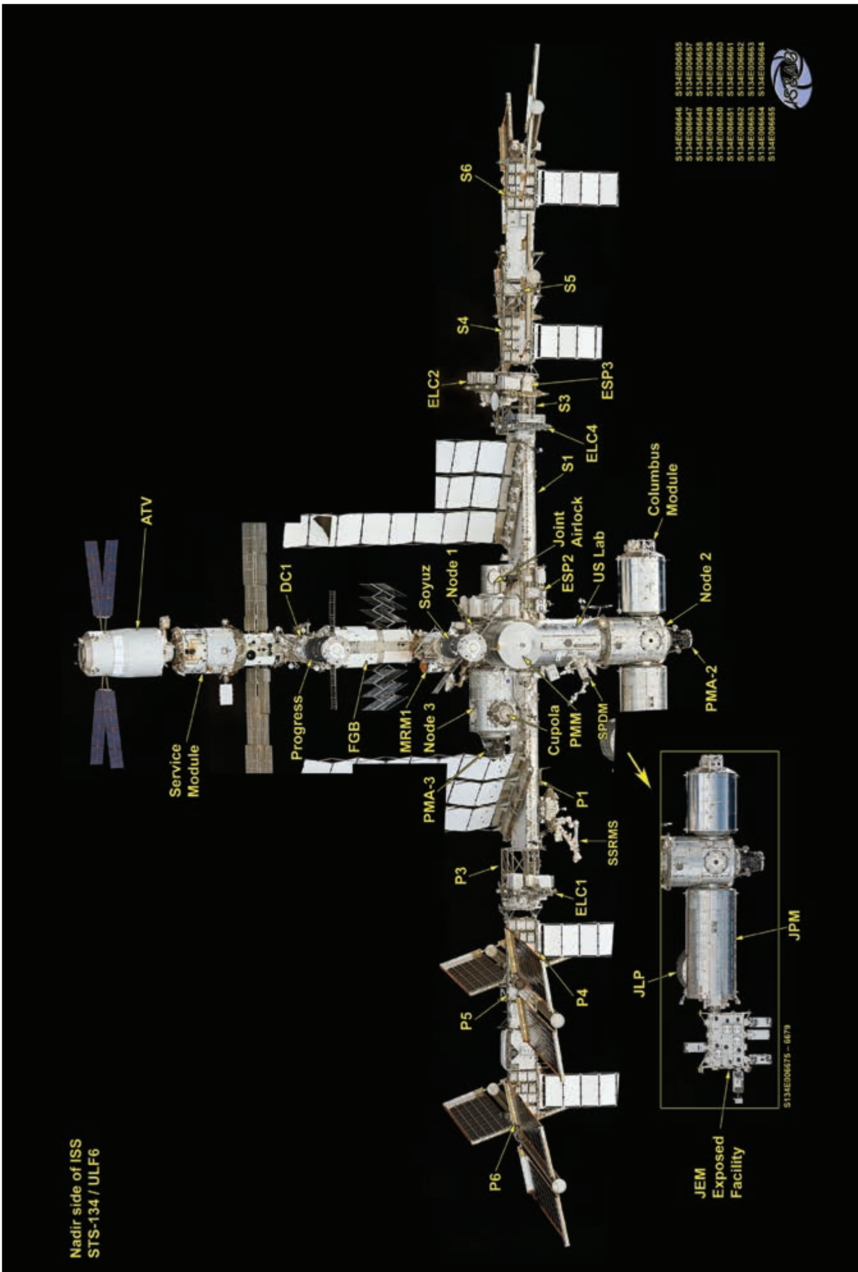
Data from SAGE III observations of the Dragon cargo vehicle visiting the ISS from June 2017 to January 2018. Results show higher than anticipated contamination levels. The Space Environments Team uses these data to develop an improved understanding of the causes of these high contamination levels.

Molecular contamination as a result of visiting vehicles and external payloads can negatively impact performance, mission success, and science utilization. Examples of contamination include outgassing, vacuum leakage, and thruster plume-induced contamination. As the ISS has become a platform for numerous external and internal remote sensing instruments, characterization of the contamination environment and potential risks to sensor systems has become a priority.

Following the arrival of the Stratospheric Aerosol and Gas Experiment III (SAGE III) in 2017, the ISS gained a new capability in active contamination monitoring. SAGE III measures the Earth's ozone and other gases and aerosols in the atmosphere through "limb scattering" of solar radiation. Equipped with eight Thermoelectric Quartz Crystal Microbalances (TQCMs), SAGE III TQCM data indicates that the majority of ISS permanent modules and visiting vehicles make minimal contributions to contamination. The TQCMs also measured elevated outgassing associated with the docked Dragon cargo vehicle, prompting the Space Environments Team of the ISS Program Office to revise contamination identification methods, visiting vehicle requirements, and contamination models based on SAGE III data. The ISS Program is working with SpaceX to mitigate contamination from future visiting Dragon spacecraft.

Clouds over the Crozet Islands. The Crozet Islands are a part of an archipelago in the Southern Indian Ocean near Antarctica. These islands have dramatic relief against the surrounding oceans, rising over 2500 ft above sea level. Wind traveling across the Indian Ocean acts as a smooth flowing fluid and moves around the tall islands. The result of this wind flow can be visualized by the V-shaped clouds on the leeward or downwind direction of the islands. A sliver of Île aux Cochons, or Pig Island in French, is seen in this photo, causing the occurrence of the ship wave clouds.

ISS Assembly Complete



Legend

ATV - Automated Transfer Vehicle
DC1 - Docking Compartment 1
ELC - Expedite the Processing of Experiments to Space Station (EXPRESS) Logistics Carrier
ESP - External Stowage Platform
FGB - Functional Cargo Block
JEM - Japanese Experiment Module
JLP - Japanese Experiment Logistics Module Pressurized Section
JPM - Japanese Pressurized Module
MRM1 - Mini-Research Module 1
P1-P6 - Port attachment points
PMA - Pressurized Mating Adapter
PMM - Permanent Multipurpose Module
S1-S6 – Starboard attachment points
SPDM - Special Purpose Dexterous Manipulator
SSRMS - Space Station Remote Manipulator System
STS - Space Transportation System
ULF – Utilization/Logistics

Facilities

ISS Research Facilities enable scientific investigations and are defined as:

1. Available aboard ISS or as a sortie to ISS for long periods of time (i.e., more than a single increment)
2. Can be scheduled for use by investigators OR provide an interface for connecting investigations to the ISS/environment by other than the hardware's original developer/owner.

Circling the Earth every 90 minutes in a low-Earth orbit, covering over 90 percent of the planets habitable land mass, the ISS provides a unique vantage point for collecting Earth and space science data. From an average altitude of about 400 km (248.5 miles), detailed data regarding the space environment, land features, environmental changes and land use taken from the ISS can be layered with other sources of data, such as orbiting satellites and aerial photogrammetry, to compile the most comprehensive information available. Facilities in this section show some of the current and growing capabilities afforded by the ISS in the following fields of research: glaciers, agriculture, urban development, natural disaster monitoring, atmospheric observations, and space radiation.

ISS Windows

View of Russian Extravehicular Activity 45A seen through Cupola Window 7. lOleg Kononenko secured in a yakor foot restraint attached to Cargo Boom Module-1, is visible near the worksite on the docked Soyuz MS-09 spacecraft exterior (ISS057E131561).

There are more than 30 windows with varied optical properties within the ISS, providing many viewing opportunities for researchers. Variability within these properties include pane material, thickness, coating, and the presence or absence of pressure covers that determine optical quality. Each window is subject to strict quality control and monitoring because structural flaws increase the possibility of fractures caused by Micrometeoroid Orbital Debris (MMOD).

The Cupola, an observatory module attached to the nadir side of the International Space Station, provides a panoramic observation and work area for the crew to support operations outside the station, such as robotic activities, visiting vehicles, and spacewalks. Its seven windows come equipped with shutters to protect them from contamination and MMOD. While the Cupola was not intended expressly for Earth observations, it has become the most commonly used ISS viewing port for CEO activities.

Potential proposers of instruments that require specific window properties or fields of view are strongly encouraged to contact the International Space Station Program or the ISS U.S National Laboratory early in the conceptual design process to verify that the desired viewing locations are appropriate and available. More information on the design process can be found at https://www.nasa.gov/mission_pages/station/research/research_information.html.

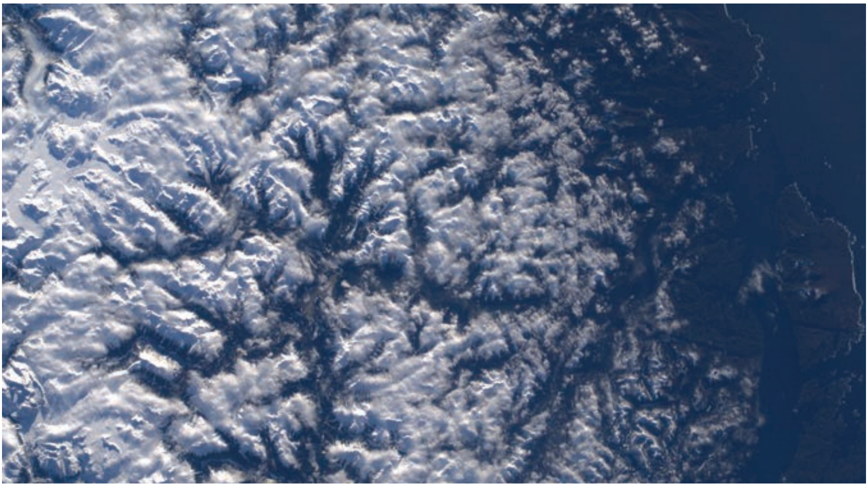
Internal Facilities

Overall view of WORF in the U.S. Laboratory taken on January, 15, 2015 (ISS034E029941).

Window Observational Research Facility (WORF), Launched April 2010

The WORF was delivered to the ISS in April 2010 on the STS-131 mission of Space Shuttle Discovery. It was installed and prepped in the Destiny Laboratory. The WORF occupies the location in the U.S. Lab adjacent to the highest quality optical window ever installed on a human-tended spacecraft. The WORF provides a unique ISS facility for conducting crew-tended or automatic Earth observation and scientific research. It is a multipurpose facility that provides structural support hardware, avionics, thermal conditioning, and optical quality protection in support of a wide variety of remote-sensing instruments and scientific investigations. The arrival of the WORF has allowed astronauts to permanently remove a protective, non-optical "scratch pane" on the window, which had often blurred images. The exterior surface of the WORF window is protected by a closeable shutter for protection from contamination from visiting vehicles. This shutter can be commanded to open and close from the ground, providing 24/7 science data collection capability (within ISS operational and contamination mitigation flight rules).

The WORF also provides a highly stable mounting platform to hold cameras and sensors steady while offering power, command, data, and cooling connections. As a facility, the WORF can provide power, data, and cooling water for up to three payloads simultaneously by interfacing with existing ISS systems. The WORF can provide data downlink at a rate on the order of 100 Mbps. Investigators can operate

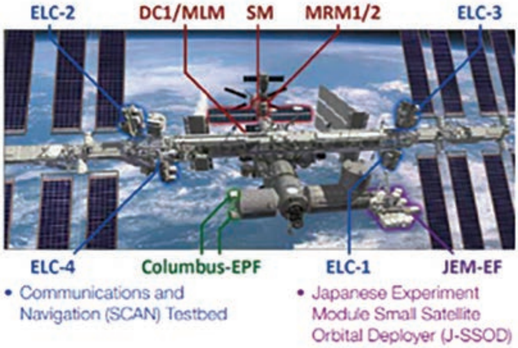


This view of British Columbia's snow-capped mountains and coastline in western Canada, captured on January 17, 2011, features an area just north of Vancouver Island, centered at 51.8 degrees north latitude and 127.9 degrees west longitude, and covering an area approximately 200 kilometers by 134 kilometers (EarthKAM Image 9362).

their payloads autonomously at their institutions with uplink and downlink data going through the Huntsville Operations Support Center at MSFC in Huntsville, AL. The general design philosophy of the WORF favors autonomous payloads, but crew members can also operate payloads from the Destiny Laboratory aisle using an externally mounted laptop computer (Scott, et al. 2003).

External Facilities

This section provides an overview of current external facilities that contribute to research in Earth observations from the microgravity environment outside the space station. As science and commercial utilization of the ISS continues to grow, this list is subject to change. For in-depth information on ISS



Graphical representation of the ISS flying toward the viewer highlights the primary locations for external facility interface infrastructure and hardware, including a subset of current ISS facilities housed at those locations.

facilities, visit space Station Research Explorer: https://www.nasa.gov/mission_pages/station/research/experiments/explorer/index.html.

Columbus External Payload Facility (ESA), Launched 2007

Columbus-External Payload Facility (Columbus-EPF) provides four powered external attachment sites for scientific payloads or facilities, and has to date been used by ESA and NASA. Each of the four attachment sites holds a mass of up to 290 kg and provides utility connections for power and data. Included with Columbus at launch, the Solar Facility was one of the first two European investigations supported by the Columbus-EPF. Currently, the Atmosphere Space Interaction Monitor (ASIM) and High Definition Earth Viewing (HDEV) systems are installed on the lower, Earth-facing external attachment sites.

Columbus EPF Resources

Location	Viewing	Payload Size	Power	Data
SOZ	Zenith	230 kg per site (sites; uses adapter CEPA)	1.25 kW at 120 VDC; 2.5 kW max	Ethernet: 10 Mbps
SOX	Ram			
SDX	Ram			
SDN	Nadir			

Kibo (JAXA), Launched 2008

The Japanese Experiment Module (JEM), known as "Kibo" (pronounced key-bow), which means "hope" in Japanese, is Japan's first manned space experiment facility. It is the largest experiment module on the ISS. This is the Japan Aerospace Exploration Agency's (JAXA's) first contribution to the ISS program. Kibo was designed and developed with a view to conducting scientific research activities on orbit.

The Kibo consists of two experiment facilities, the Pressurized Module (PM) and the Exposed Facility (EF). The EF is directly exposed to space, and it is a unique facility among ISS laboratories because it enables long-term experiments in open space as well as Earth and astronomical observations. The EF is used for research in fields such as communication, space science, engineering, technology demonstration, materials processing, and Earth observation. The PM is equipped with an airlock, allowing astronauts to move experiment devices back and forth between the PM and the EF through the airlock by manipulating the Kibo's robotic arm (JEM-RMS). Kibo provides extensive opportunities for utilization of the space environment as well as Earth remote sensing investigations.

Japanese Experiment Module (JEM) (JAXA) External Accommodations, Launched 2009

Mass Capacity	500 kg (10 standard sites, mass includes PIU adaptor); 2500 kg (3 heavy sites, mass includes PIU adaptor)
Volume	1.5 m^3
Power	3–6 kW, 113–126 VDC
Thermal	3–6 kW cooling
Low-rate data	1 Mbps (MIL-STD-1553)
High-rate data	43 Mbps (shared)
Sites available per ELC	2 Sites
Sites available to NASA	5 Sites

EXPRESS Logistics Carrier (several external locations on ISS truss)

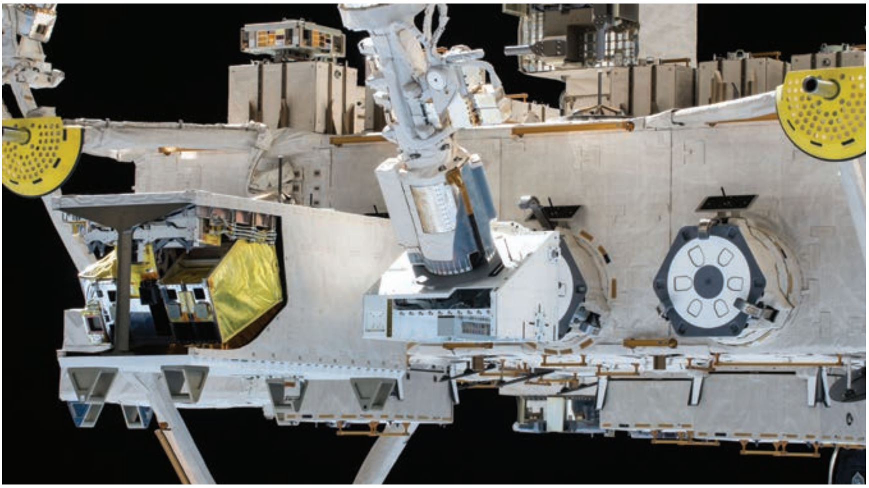
Expedite the Processing of Experiments to the Space Station (ExPRESS) Logistics Carrier (ELC) is a pallet designed to support external research hardware and store external spares (called Orbital Replacement Units, ORUs) needed over the life of ISS. Currently, four ELCs are mounted to ISS trusses, providing unique vantage points for space, technology and Earth-observation investigations. Two ELCs are attached to the starboard truss 3 (ITS-S3) and two ELCs to the port truss 3 (ITS-P3).

By attaching at the S3/P3 sites, a variety of views such as Zenith (deep space) or Nadir (Earthward) direction with a combination of ram (forward) or wake (aft) pointing allows for many possible viewing opportunities.

ExPRESS Logistics Carrier (ELC) External Research Accommodations

Mass Capacity	227 kg (500lb); 8 sites across 4 ELCs; not including adaptor plate
Volume	1.2 m^3
Power	750 W, 113–126 VDC; 500 W at 28 VDC per adapter
Thermal	Active heating, passive cooling
Low-rate data	1 Mbps (MIL-STD-1553)
Medium-rate data	6 Mbps (shared)
Sites available per ELC	2 Sites
Total ELC sites available	8 Sites

NanoRacks External Platform (NREP) (NASA), Launched 2016



This image shows the Japanese Experiment Module Remote Manipulator System (JEMRMS) moving to install the NanoRacks External Platform (NREP) on the Japanese Experiment Module—External Facility (JEM-EF) (ISS048E049803).

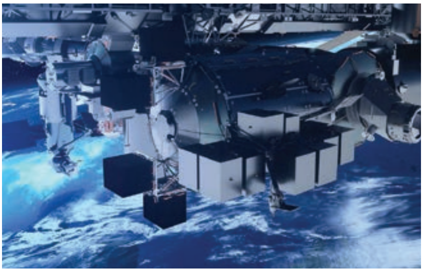
The NanoRacks External Platform is the first commercial research capability for testing science investigations, sensors, and electronic technologies in space. The NREP is located on the JEM-EF, and payloads are deployed by the Japanese Experiment Module Remote Manipulator System (JEMRMS). For more information on accessing the NREP, contact ISS U.S. National Laboratory (https://www.issnationallab.org/).

Multiple User Systems for Earth Sensing (MUSES) (NASA), Launched 2016

The Multiple User System for Earth Sensing (MUSES) is a commercial Earth imaging platform capable of hosting different remote sensing instruments such as high-resolution digital cameras and hyperspectral imaging systems for commercial and scientific applications. It hosts up to four instruments at the same time, and allows for changes, upgrades, and robotic services to be made on those instruments. MUSES performs its duties in the microgravity environment on the external ISS. For more information on accessing MUSES, contact ISS U.S. National Laboratory (https://www.issnationallab.org/).

Bartolomeo (ESA), Launch Planned 2019

Bartolomeo is aerospace company Airbus DS's new external payload-hosting facility capable of hosting multiple external payloads on the ISS and providing reliable access to low-Earth orbit for commercial and institutional customers from Europe, the U.S., and international partners throughout the life of the ISS. It will feature an unobstructed view of Earth and space, unpressurized and pressurized launch of payloads, and payload or sample return options.



The concept art above shows the Bartolomeo platform, an external payload hosting facility named after Christopher Columbus' younger brother. This payload is to be mounted on the forward side of the Columbus module. Image credit: Airbus DS)

ESA and Airbus DS established a partnership for the construction, launch, and operations of the Bartolomeo platform, scheduled to launch and begin performing its duties attached to the European Columbus module in mid-2019.

Small Satellite Deployment (NASA)

Another option of potential interest for Earth remote sensing is the use of deployable small satellites such as CubeSats, either singly or in constellations. Following construction on the ground, these small satellites can be transported to the ISS for launch into free flight and eventual re-entry to Earth's atmosphere.

Satellite	Size, Approximate mm (Inches)	Mass (Max of Deployed Satellite)	Location of Deployment
J-SODD	1U – 100 x 100 x 113.5 mm (3.9 x 3.9 x 4.7 inches) 2U – 100 x 100 x 227.0 mm (3.9 x 3.9 x 8.9 inches) 3U – 100 x 100 x 340.5 mm (3.9 x 3.9 x 13.4 inches)	1.33 Kg/1U	Deployed from ISS (JEM EF) Currently in-orbit
CYCLOPS	1117.6 x 762 x 279.4-533.4 mm (44L x 30W x 11-21H inches)	100 kg	Deployed from ISS (JEM EF) In-orbit post SpX3 launch
Space X	1U – 100 x 100 x 100 mm (3.9 x 3.9 x 3.9 inches) 2U – 100 x 100 x 200 mm (3.9 x 3.9 x 6.8 inches) 3U – 100 x 100 x 300 mm (3.9 x 3.9 x 10.7 inches)	1.33 kg/1U	Deployed from Space X prior to ISS docking Available post SpX3

ISS Pointing, Interface, and Environmental Information

ISS pointing, interface, and environmental information is presented in a guide titled, "A Researcher's Guide to: International Space Station Technology Demonstration," in the sections ISS Characteristics and ISS Accommodations – Software and Avionics, ISS Command and Data Handling.

Funding, Developing and Launching Research to ISS

There are several sources of funding available to scientists to be used for research, payload development, payload processing at NASA facilities, in-orbit operation, and more. Once a payload has been selected for development, engineering and operations staff in the ISS Program Office are available to work with payload teams through the design, test, certification, build, and launch phases prior to beginning mission operations on ISS. More detailed information on this process, and information on current and planned launch vehicles, is available at https://www.nasa.gov/mission_pages/station/research/research_information.html.

In general, NASA funding for space station use is obtained through NASA Research Announcements (NRAs). Funding for other government agencies, private, and non-profit use of the space station is obtained through research opportunities released by ISS U.S. National Laboratory. Space Station International Partner funding can be obtained through their respective processes.

Potential proposers to any NASA program announcement should contact the relevant Program Scientist to discuss the appropriateness of their sensor concept to the specific solicitation and for contacts within the ISS Program Office to discuss expected development costs for their proposal budgets.

National Funding Sources

NASA SMD (ROSES)

NASA's Science Mission Directorate (SMD) provides Research Opportunities in Space and Earth Sciences (ROSES) through the Applied Science Program. The Applied Sciences Program promotes and funds activities to discover and demonstrate innovative uses and practical benefits of NASA Earth science data, scientific knowledge, and technology.

NASA SMD EXPLORER/SALMON

SMD also solicits for Missions of Opportunity via a Stand Alone Mission of Opportunity Notice (SALMON) and the Explorers Program. The mission of the Explorers Program is to provide frequent flight opportunities for world-class scientific investigations from space utilizing innovative, streamlined and efficient management approaches within the heliophysics and astrophysics science areas. The program seeks to enhance public awareness of, and appreciation for, space science and to incorporate educational and public outreach activities as integral parts of space science investigations.

NASA SMD Earth Venture (EV)

The Earth System Science Pathfinder (ESSP) program, https://essp.nasa.gov/, within SMD is a science-driven program designed to provide an innovative approach to Earth science research by providing periodic, competitively selected opportunities to accommodate new and emergent scientific priorities. ESSP Projects include developmental, high-return Earth Science missions including advanced remote sensing instrument approaches to achieve these priorities and often involve partnerships with other U.S. agencies and/or with international science and space organizations. These projects are capable of supporting a variety of scientific objectives related to Earth science, including the atmosphere, oceans, land surface, polar ice regions and solid earth. Projects include development and operation of space missions, space-based remote sensing instruments for missions of opportunity, and airborne science missions, and the conduct of science research utilizing data from these missions. ESSP missions encompass the entire project life-cycle from definition, through design, development, integration and test, launch, operations, science data analysis, distribution and archival.

ESSP is home to NASA's Earth Venture (EV) class of missions: a series of uncoupled, relatively low-to-moderate cost, small- to medium-sized, competitively selected, full-orbital missions (EVM); instruments for orbital missions of opportunity, including the ISS (EVI); and sub-orbital projects (EVS).

More information on NASA funding opportunities can be found at https://science.nasa.gov/researchers/sara/grant-solicitations.

ISS U.S. National Laboratory

In 2011, NASA finalized a cooperative agreement with the Center for the Advancement of Science in Space to manage the International Space Station U.S. National Laboratory (ISS National Lab). The independent, nonprofit research management organization ensures the station's unique capabilities are available to the broadest possible cross section of U.S. scientific, technological and industrial communities.

The ISS National Lab develops and manages a varied research and development portfolio based on U.S. national needs for basic and applied research. It establishes a marketplace to facilitate matching research pathways with qualified funding sources and stimulates interest in using the national lab for research and technology demonstrations and as a platform for science, technology, engineering and mathematics education. The goal is to support, promote and accelerate innovations and new discoveries in science, engineering and technology that will improve life on Earth.

More information on ISS National Lab, including proposal announcements, is available at www.issnationallab.org.

Other Government Agencies

Potential funding for research on the ISS is also available via governmental partnerships with ISS U.S. National Laboratory and includes (but is not limited to) such government agencies as:

- Defense Agency Research Projects Agency (DARPA)
- Department of Energy (DOE)
- Department of Defense (DOD)
- National Science Foundation (NSF)
- National Institutes of Health (NIH)
- U.S. Department of Agriculture (USDA)

International Funding Sources

Unique and integral to the ISS are the partnerships established between the United States, Russia, Japan, Canada and Europe. All partners share in the greatest international project of all time, providing various research and experiment opportunities for all. These organizations – Japan Aerospace Exploration Agency (JAXA), Canadian Space Agency (CSA), ESA (European Space Agency), Russian space agency Roscosmos, Centre National d'Etudes Spatiales (CNES), and the German Aerospace Center (DLR) – provide potential funding opportunities for international scientists from many diverse disciplines.

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Acronyms

ASI	Italian Space Agency
ASIM	Atmosphere-Space Interactions Monitor
BAD	Broadcast Ancillary Data
C&DH	Command and Data Handling
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CATS	Cloud Aerosol Transport System
CEO	Crew Earth Observations
CEPA	Columbus External Payload Adapter
CLARREO	Climate Absolute Radiance and Refractivity Observatory
COTS	Commercial off the Shelf
CST	Crew Space Transportation
DESIS	DLR Earth Sensing Imaging Spectrometer
DHPU	Data Handling and Power Unit
DLR	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt)
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
ECLSS	Environmental Control & Life Support Systems
EEU	Experimental Exchange Unit
ELC	EXPRESS Logistics Carrier
EPF	External Payload Facility
EREP	Earth Resources Experiment
ESA	European Space Agency
ESRS	Earth Science and Remote Sensing Unit
EUSO	Extreme Universe Space Observatory
EV	Earth Venture
EVA	Extravehicular Activity (spacewalk)
EXPRESS	Expedite the Processing of Experiments for Space Station Rack
FRAM	Flight Releasable Attachment Mechanism
FOV	Field of View
GEDI	Global Ecosystem Dynamics Investigation
GSD	Ground Sample Distance
HD	High Definition
HDEV	High Definition Earth Viewing
HEIST	Hyperspectral Earth Imaging System Trial
HICO	Hyperspectral Imager for the Coastal Ocean

HISUI	Hyperspectral Imager Suite
HREP	HICO and RAIDS Experiment Payload
ICD	Interface Control Document
ICU	Integrated Communications Unit
IDC	International Disasters Charter
ISERV	ISS SERVIR Environmental Research and Visualization System
ISS	International Space Station
ISSAC	ISS Agricultural Camera
JEM	Japanese Experiment Module
JEM-EF	JEM Exposed Facility
JPL	Jet Propulsion Laboratory
LAN	Local Area Network
LEO	Low Earth Orbit
LIDAR	Light Detection and Ranging
LIS	Lightning Imager Sensor
LOS	Loss of Signal
MCC	Mission Control Center
MMIA	Miniature Multispectral Imaging Array
MMOD	Micrometeoroid Orbital Debris
MSFC	Marshall Space Flight Center
MSS	Mobile Servicing System
MUSES	Multiple User Systems for Earth Sensing
NASA	National Aeronautics and Space Administration
NRL	Naval Research Lab
OCO-3	Orbiting Carbon Observatory-3
PHILLS	Portable Hyperspectral Imager for Low Light Spectroscopy
PIM	Payload Integration Manager
PL MDM	Payload Multiplexer De-Multiplexer
PM	Pressurized Module
POIC	Payload Operation Integration Center
PRCU	Payload Rack Checkout Unit
RAIDS	Remote Atmosphere and Ionospheric Detection Systems
RIM	Research Integration Manager
RMS	Robotic Manipulator System

ROSES	Research Opportunities in Space and Earth Science
SAGE III	Stratospheric and Aerosol Gas Experiment III
SALMON	Stand Alone Mission of Opportunity Notice
SE	Safety Engineer
SIR-C/X-SAR	Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar
SMD	Science Mission Directorate
SMILES	Superconducting Submillimeter-Wave Limb-Emission Sounder
SQM	Strange Quark Matter
SRTM	Shuttle Radar Topography Mission
STP-H5 LIS	Space test Program-H5-Lightning Imaging Sensor
SwRI	Southwest Research Institute
TDRSS	Tracking and Data Relay Satellite System
TEA	Torque Equilibrium Attitude
TKSU	Tskuba Space Center (Japan)
TLE	Transient Luminous Events
TQCM	Thermoelectric Quartz Crystal Microbalances
TREK	Telescience Resource Kit
TRL	Technology Readiness Levels
TRMM	Tropical Rainfall Measuring Mission
TSI/SSI	Total Solar Irradiance/Spectral Solar Irradiance (TSIS-1)
UHECR	Ultra-High-Energy-Cosmic Ray
USGS	United States Geological Survey
UV	Ultra Violet
VDC	Voltage Direct Current
VNIR	Visible Near Infrared
WORF	Window Observational Research Facility

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