



The International Space Station, A Unique Platform for Earth Observation

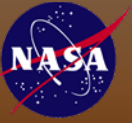
Dr. William L. Stefanov

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and Astromaterials Research and Exploration Science Division
NASA Johnson Space Center, Houston, Texas, USA

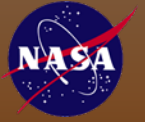
william.l.stefanov@nasa.gov



Why do humans explore?



Exploration technology and discovery in new environments are linked – but science takes more time



Captain James Cook, HMS *Resolution*, Ca. 1771

Charles Darwin, HMS *Beagle*, ca. 1831 (OOS 1859)

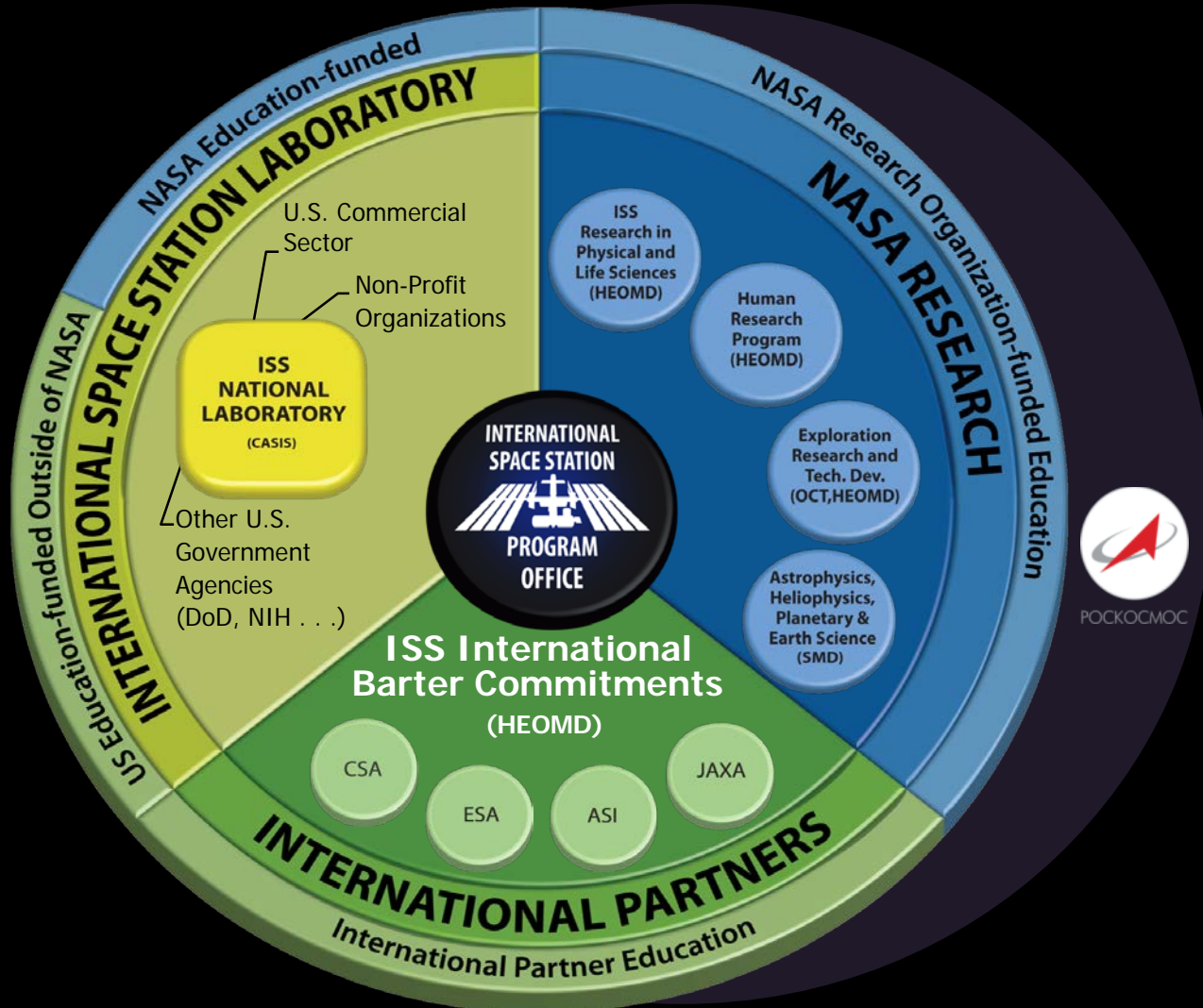
Nations Explore... in order to advance



- Exploration drives technological breakthroughs and scientific discoveries that benefit society.
- Without exploration, the cycle of advancement is broken.
- The ISS Partnership has transformed exploration from an effort for the advancement of individual nations, to an endeavor committed to the advancement of humankind.

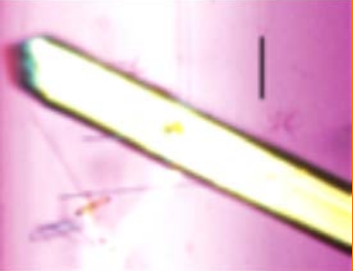
SPONSORSHIP

Funding Sources



For more information on research sponsorship and funding, see:
http://www.nasa.gov/mission_pages/station/research/funding_information.html

What are we doing on ISS today?



National Lab

NASA

Biology and Biotechnology

Human Research

Physical Sciences

Tech Demos

Earth Science

Astrophysics

Education





Remote sensing of Earth: Why ISS?



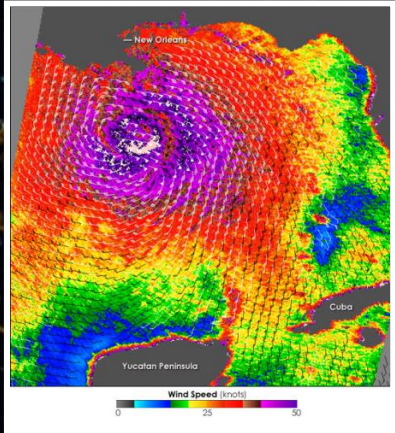
Polar orbit

- Sun-synchronous – designed for long term repeatability of data
- Typically nadir viewing, crosses every point on Earth ~ 12-14 days near local solar noon/local midnight
- Landsat series collecting data since 1972
- Pointing capability, satellite constellations

Inclined Equatorial Orbit: ISS

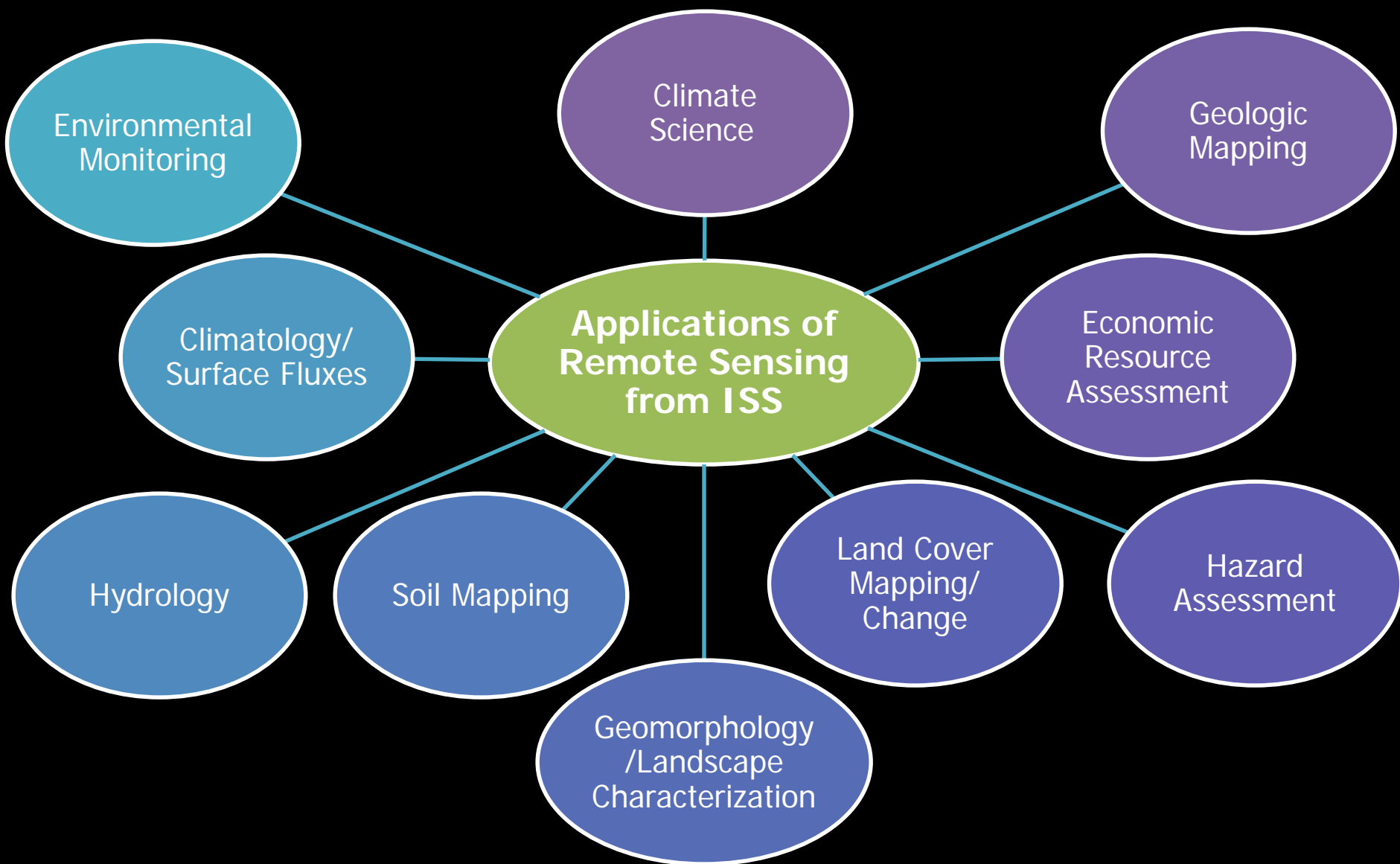
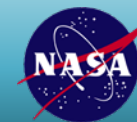
- Sun-asynchronous – similar illumination 3-4 days every 90 days
- Nadir to highly oblique imagery possible from hand-held cameras, WOLF, external sensors
- Provides opportunity to collect unique datasets for scientific study, disaster response
- Data is complementary to polar-orbiting satellite data
- Opportunity for instrument cross-calibration

Earth Science



- Platform with full services (power, data, thermal) in LEO (~400 km)
 - All geographic locations between 51.6 North and South latitude
 - 85% of the Earth's surface
 - 95% of the world's populated landmass every 1-3 days
 - External sites for nadir, zenith, ram and wake
 - Variable (and precessing) lighting (changes with subsequent passes)
 - Well-suited for test bed concepts with hardware change out and upgrades

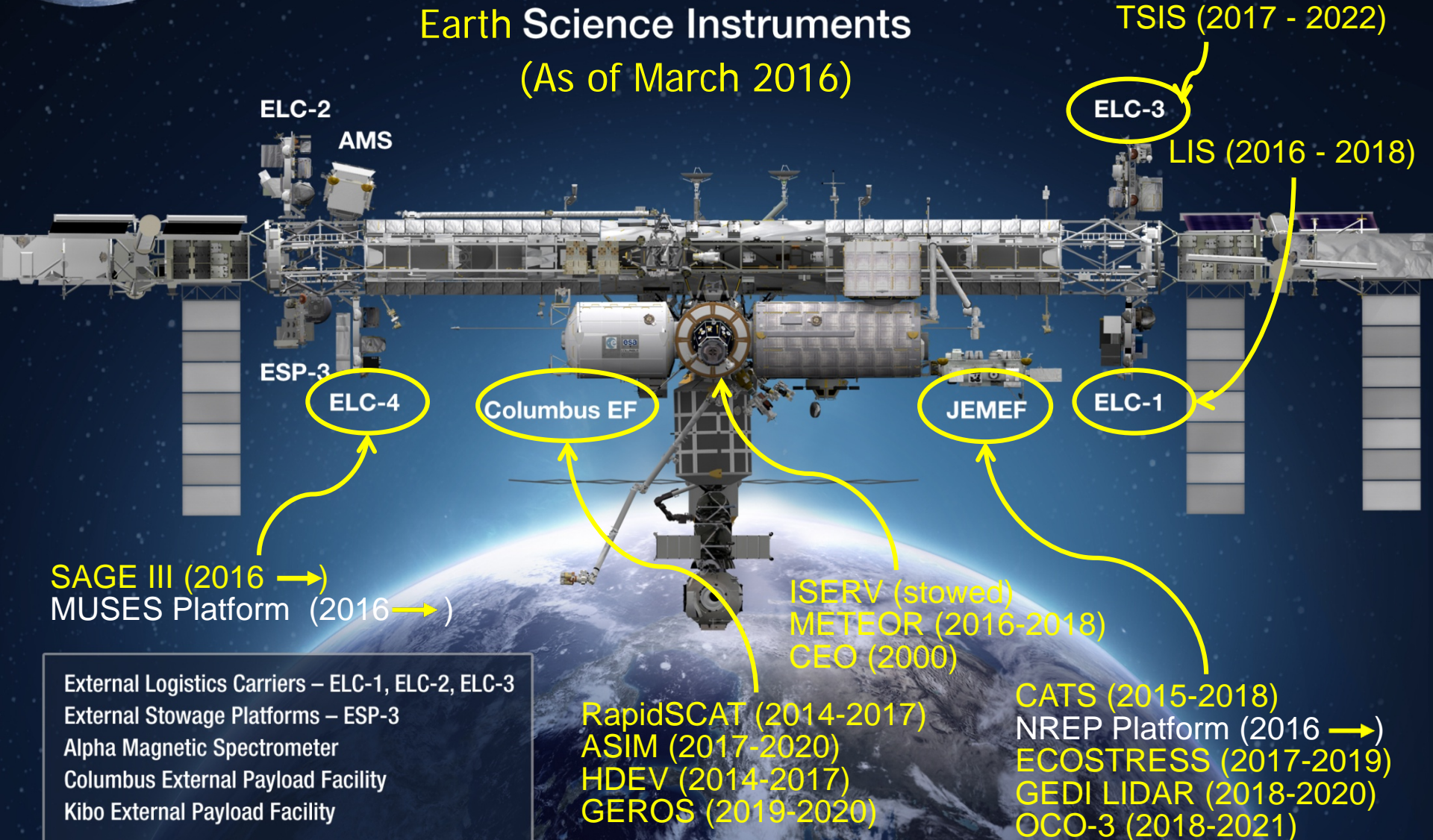
Applications of Remote Sensing from ISS





International Space Station

Earth Science Instruments (As of March 2016)



- External Logistics Carriers – ELC-1, ELC-2, ELC-3
- External Stowage Platforms – ESP-3
- Alpha Magnetic Spectrometer
- Columbus External Payload Facility
- Kibo External Payload Facility

ISS Extension to at least 2024



- Obama Administration committed in 2014 to extend space station operations to at least 2024
- 2015, Congress authorized this extension
- ISS International Partners Japan, Canada and Russia have since announced their support for this extension. ESA (the European Space Agency) is currently working an extension through their Ministerial process.
- Adding four years from 2020-2024 nearly doubled the opportunity for hosting instruments on ISS
- We are not beginning decommissioning and the ISS engineering life is at least 2028

INTERNAL INSTRUMENTS



NASA Payloads – Crew Earth Observations

Sensor: Crew Earth Observations (CEO)

Location: internal, Station windows

Sponsor/Funding: ISSP

Prime Mission: collection of Earth imagery in support of disaster response, and dynamic events with other ISS sensor systems. Also supports education/outreach and focused short-term science objectives.

ISS Timeframe: 2000-2024

Principal Investigator: William L. Stefanov, JSC

Pointing capability: variable, dependant on window and lens

Geometric resolution: variable, depends on lens
< 3 m/pixel with 1000 mm lens to > 30 m/pixel with 110 mm and shorter lenses

Spectral sensitivity: visible RGB, poorly constrained bandpass (potential for NIR imagery using modified camera)

Scene Size: variable, depends on lens, ISS altitude

Data take to availability time: ~ 24 hours for full resolution d
may be possible to expedite

Data availability: Public; <http://eol.jsc.nasa.gov>

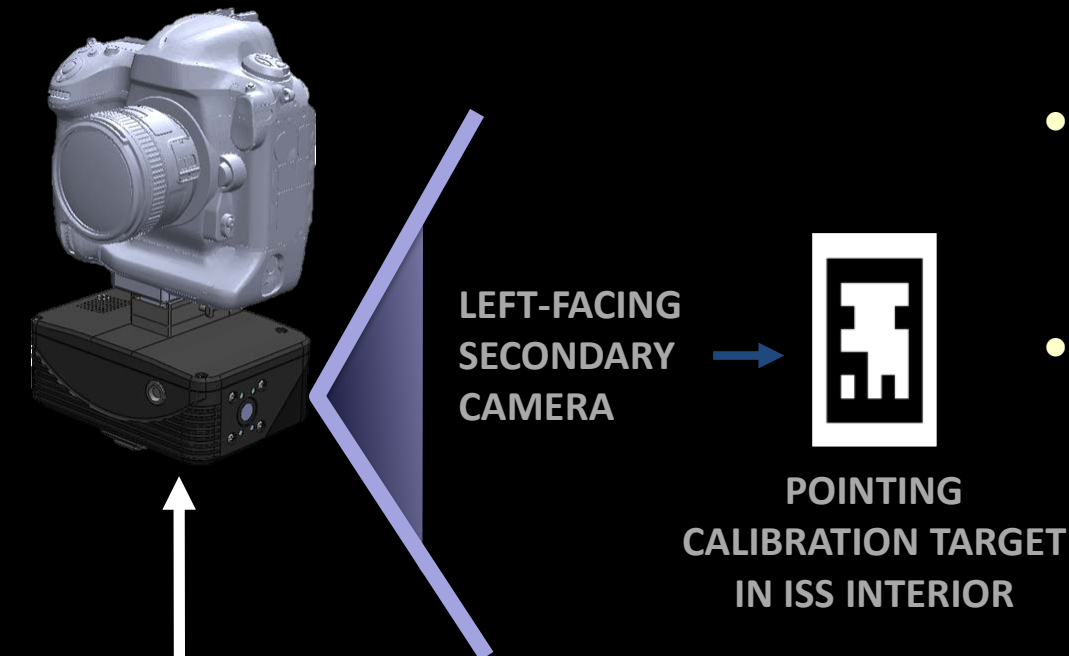


ISS036-E-5769

GeoCam Space System – late 2016/early 2017



GeoSens Hardware (NASA Ames)



LG Nexus 5



- Pointing Calibration Targets mounted in cupola
 - Ideally, semi-permanent mounting to avoid recurring setup time
- During photography, ensure some calibration target is occasionally in view of secondary camera
 - (Example: In view for at least 1 second every 5 minutes)
 - Given proper target placement, this may happen without explicit astronaut attention
 - Sensor package can use an audible tone to indicate rare cases when astronaut attention is needed
 - Trade-off: More targets vs. higher chance calibration activity is needed



GeoCam Space System – late 2016/early 2017



GeoRef Software (NASA Ames)

Go to **Tips:** << >> Use "Go to Location" to zoom the map to the neighborhood of your overlay.

Cursor (Lat, Lon): (53.48845408163873, 108.57719421386719)

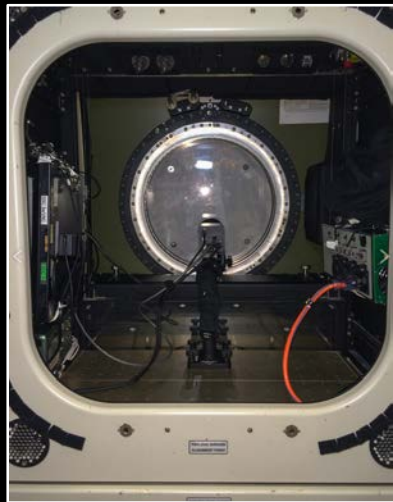
Reasonable rotation and geolocation to base image with only 3 tie points – developing fully automated geolocation

Meteor Composition Determination (METEOR)

Description: Meteor's mission objective is to fly a visible spectroscopy instrument to the ISS for the primary purpose of observing meteors in Earth orbit. Meteor uses image analysis to provide information on the physical and chemical properties of the meteoroid dust, such as size, density, and chemical composition. Meteor plans to operate for 2 years (as allowed by science priorities) in the WORF volume.

Payload Description:

- High-resolution video and still images of atmosphere with software triggering for bright "events"
- Camera system collects information in visible wavelengths (up to 700 nm) for spectral analysis of Fe, Ca, Mg, Na emission lines
- Mounted in Window Observational Research Facility (WORF)



Research Overview:

- Meteors cross the field of view of the observer's instrument and are recorded either photographically or electronically. Spectral measurements are made by a spectrograph, which records all wavelengths instantaneously.
- Investigators can then determine elemental abundances and temperatures by comparing known synthetic spectra to observed spectra.
- Meteor provides a continuous monitor of meteor interaction with the Earth's atmosphere without limitations of the ozone absorption.
- The resultant data aims to record the first measurement of meteor flux and allows for monitoring of carbon-based compounds. Investigation of meteor elemental composition is important to our understanding of how the planets developed.

EXTERNAL INSTRUMENTS

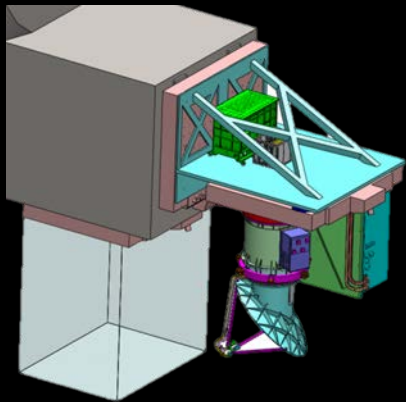
RapidScat on ISS



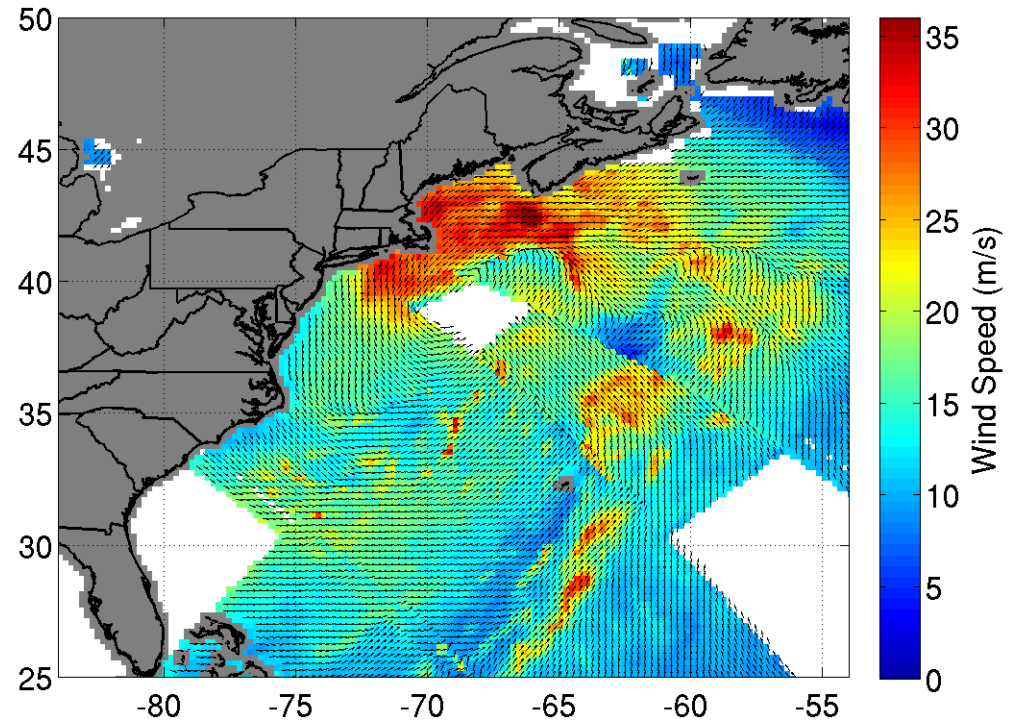
Description: Fly a radar scatterometer to continue ocean vector winds (OVW) measurements and to sample at all times of day enabled by ISS orbits (in contrast to twice a day sampling of sun-synchronous polar orbits) to observe diurnal variability of ocean winds and sea surface interaction not observable before

Objectives:

- Continue more than 10-year Ku-band based vector winds observations
- Investigate the global diurnal cycle and remove the diurnal effect on scatterometer-based ocean vector winds
- Improve cross-calibration of and provide additional measurements to the international OVW constellation



RapidScat Juno UTC 27-Jan-2015 01:59:29 to 27-Jan-2015 11:15:13



Source: <http://cdn.phys.org/newman/gfx/news/hires/2015/1-nasameasured.png>

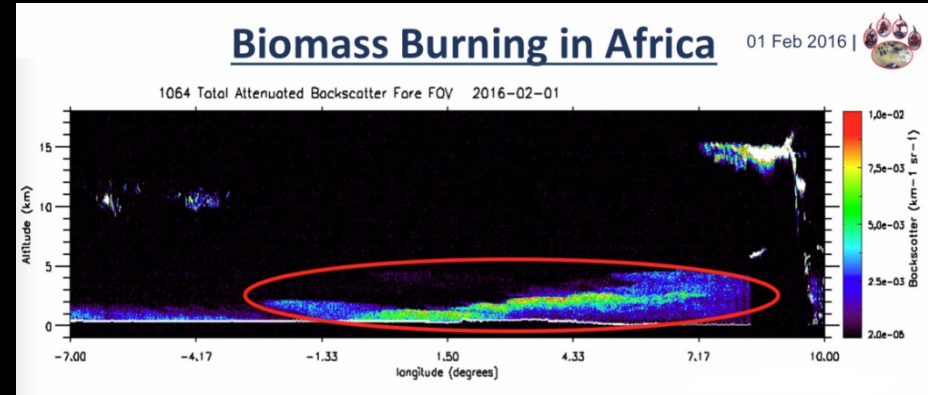
Payload: Refurbished SeaWinds EM scatterometer hardware with modification/augmentation to meet ISS payload accommodation and operation requirements and certified for flight and operations

- H-pol and V-pol pencil beams looking at about 45° from nadir, scanning at about 18 rpm with 0.75 m (D) reflector
- 800-1000 km swath, covering within $\pm 52^\circ$ latitude in 48 hrs
- Wind resolution comparable to QuikSCAT
- Mass: 200 kg, Power: 250 W; Data Rate: 40 kbps, continuous

Cloud-Aerosol Transport System (CATS)

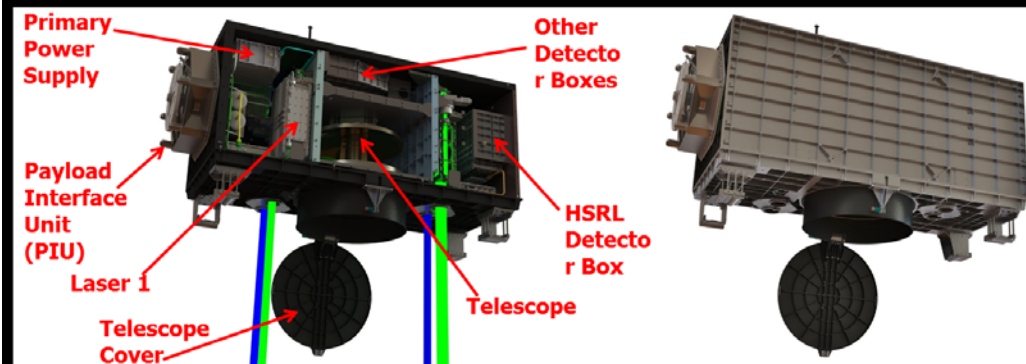
Key Science Objectives

- Demonstrate multi-wavelength aerosol and cloud retrievals.
- Provide cloud and aerosol data to help bridge the gap between CALIPSO and future missions.
- Enable aerosol transport models with near real-time data downlink from ISS
- The ability of an aerosol plume to transport long distances is determined by its injection height relative to the local planetary boundary layer (PBL).
- Passive aerosol measurements from space provide valuable constraints on column aerosol loading.
- However, models lack observational constraints on vertical distribution.
- ISS orbit is intriguing for tracking of plumes and study of diurnal effects (something not possible with A-Train orbit).



- **CATS employs 2 high repetition rate lasers**
 - One operates at 532, 1064 nm
 - Second is seeded to provide narrow linewidth for HSRL measurements and frequency-tripled for use at 355 nm
- **CATS has a 60 cm beryllium telescope with narrow field-of-view (FOV)**
 - 4 instantaneous fields of view (IFOV)

Laser 1 Type	Nd: YVO ₄
Laser 1 Wavelengths	532, 1064 nm
Laser 1 Rep. Rate	5000 Hz
Laser 1 Output Energy	~1 mJ/pulse
Laser 2 Type	Nd: YVO ₄ , seeded
Laser 2 Wavelengths	355, 532, 1064 nm
Laser 2 Rep. Rate	4000 Hz
Laser 2 Output Energy	~2 mJ/pulse
Telescope Diameter	60 cm
View Angle	0.5 degrees
Telescope FOV	110 microradians



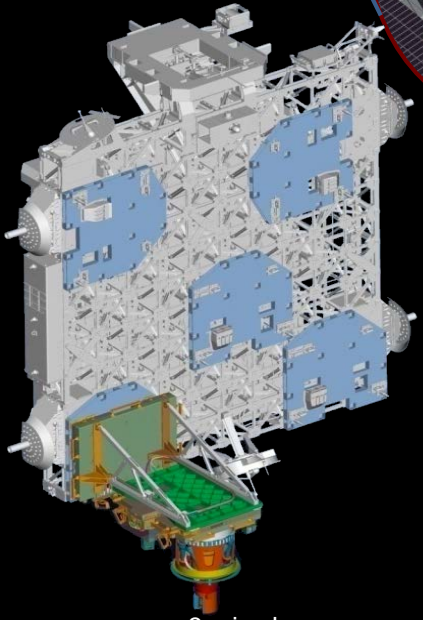
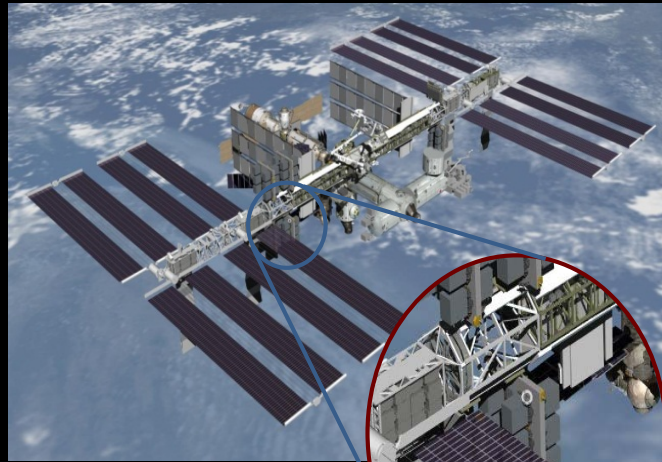


SAGE III on ISS Project Description

www-sage3oniss.larc.nasa.gov

SAGE III on ISS directly supports NASA Strategic Goals to extend and sustain human activities across the solar system; expand scientific understanding of the Earth and the universe in which we live

Primary Science Objective:
Monitor the vertical distribution of aerosols, ozone and other trace gases in Earth's stratosphere and troposphere to enhance understanding of ozone recovery and climate change processes in the upper atmosphere



www-sage3oniss.larc.nasa.gov

Mission Implementation

Partners	LaRC JSC/ISSP ESA	2016
Risk	NPR 7120.5D/NM7120.81 Category 3 / NPR 8705.4 Payload Risk Class C	
Launch	2016	
Orbit	ISS Mid-Inclination orbit	
Life	3 years (nominal) / ISS manifest through 2024 for extended mission	
Payload	Sensor Assembly (LaRC), Hexapod (ESA), CMP (LaRC), ExPA (JSC/ISS), ICE (LaRC), HEU (ESA), IAM (LaRC), DMP (LaRC) Nadir Viewing Platform (LaRC)	
Mass & Power	540 W (CBE, mix between 120Vdc and 28 Vdc) 460 kg (CBE)	

Orbiting Carbon Observatory (OCO-3) Project Overview



Primary Science Objectives

- Collect the space-based measurements needed to quantify variations in the column averaged atmospheric carbon dioxide (CO_2) dry air mole fraction, X_{CO_2} , with the precision, resolution, and coverage needed to improve our understanding of surface CO_2 sources and sinks (fluxes) on regional scales (≥ 1000 km).
Measurement precision and accuracy requirements same as OCO-2
Operation on ISS allows latitudinal coverage from 51 deg S to 51 deg N

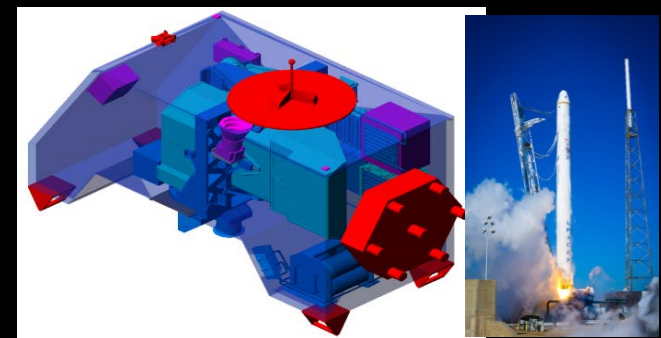
Major Features:

- Category 3 mission per NPR 7120.5E
- Risk classification C per NPR 8705.4
- High-resolution, three-channel grating spectrometer (JPL)
- Partnership between SMD and HEOMD
- Deployed on the International Space Station
- Launch Readiness: TBD



OCO-3 Requirements in Payload Interface Agreement

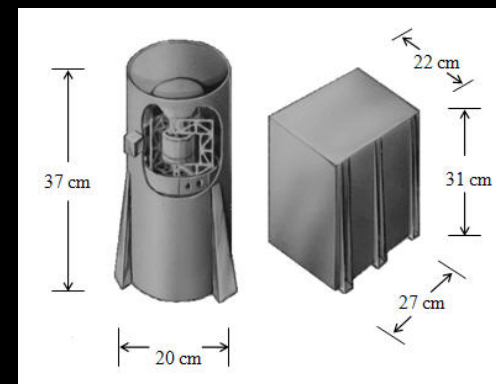
Mass	500 kg
Power	600 W
Data Rate	3 Mbps
Volume	1.85 m x 1.0 m x 0.8 m
Thermal	Fluid Cooling Loop



Lightning Imaging Sensor (LIS) on ISS

Mission Overview

- NASA developed and demonstrated space-based lightning observation as a remote sensing tool under Earth Observing System (EOS) and Tropical Rainfall Measuring Mission (TRMM) (*LIS still operational on TRMM*).
- LIS on the ISS will extend TRMM time series observations, expand latitudinal coverage, and provide real time observations in support of important and pressing science and applications objectives.
- Integrate as hosted payload on DoD Space Test Program (STP-H5)



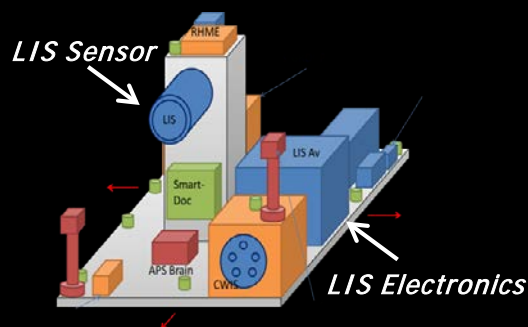
LIS Sensor Head and Electronics Unit
(20 kg, 30W, 128x128 CCD, 1 kB/s)

Measurement

- LIS measures global lightning (*amount, rate, radiant energy*) during both day and night, with storm scale resolution, millisecond timing, and high, uniform detection efficiency.
 - LIS daytime detection is both unique and scientifically important (>70% occurs during day).
 - Only LIS globally detects TOTAL (*both cloud and ground*) lightning with no land-ocean bias.

Science and Application Objectives

- Lightning is quantitatively coupled to both thunderstorm and related geophysical processes.
- Therefore lightning observations provide important gap-filling inputs to pressing Earth system sciences issues in a wide range of disciplines (e.g., *weather, climate, atmospheric chemistry, lightning physics*).
- Real time observations will be provided to operational users.
- LIS data is the "Gold Standard" for global lightning climatology.



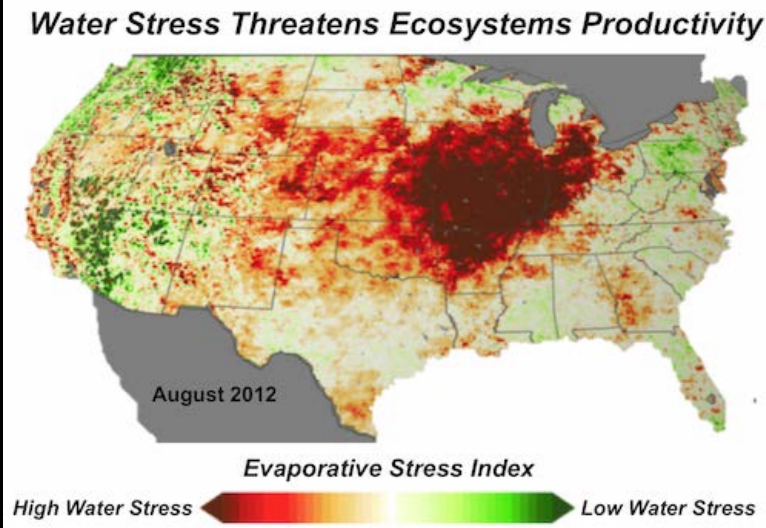
STP-H5 (notional concept)



ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)

Description: Multispectral thermal infrared sensor mounted on JEM-EF to measure the brightness temperature of plants, and use that information to better understand how much water plants need and how they respond to stress (evapotranspiration dynamics).

Parameter	Science Requirement at 400 km	Expected Instrument Capability at 400 km
Ground Sample Distance (m) Crosstrack x Downtrack at nadir	≤ 100 x ≤100	≤69 x ≤38
Swath width (ISS nominal altitude range is 385 to 415 km)	≥360	400
Wavelength range (μm)	8-12.5	8-12.5
Number of bands	≥3	≥5
Radiometric accuracy (K@300K)	≤1	≤0.5
Radiometric precision (K@300K)	≤0.3	≤0.15
Dynamic Range (K)	270-335	200-500
Data collection	CONUS, twelve 1,000 x1,000 km key climate zone and twenty-five Fluxnet sites for all opportunities. On average 1 hour of science data per day	≥1.5 hours per day of science data



Science Questions:

- How is the terrestrial biosphere responding to changes in water availability?
- How do changes in diurnal vegetation water stress impact the global carbon cycle?
- Can agricultural vulnerability be reduced through advanced monitoring of agricultural water consumptive use and improved drought estimation?

Science Objectives:

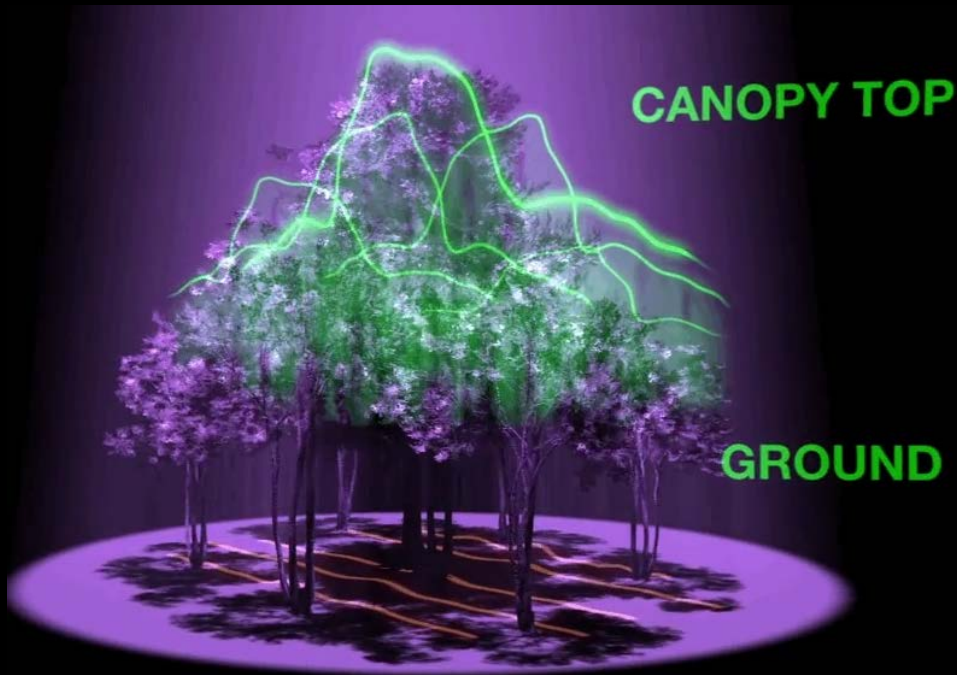
- Identify critical thresholds of water use and water stress in key climate sensitive biomes (e.g., tropical/dry transition forests, boreal forests);
- Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle;
- Measure agricultural water consumptive use over CONUS at spatiotemporal scales applicable to improving drought estimation accuracy.

Global Ecosystem Dynamics Investigation Lidar (GEDI)

Description: Active sensor system to characterize the effects of changing climate and land use on ecosystem structure and dynamics to enable radically improved quantification and understanding of the Earth's carbon cycle and biodiversity. GEDI will provide the first global, high resolution observations of forest vertical structure.

Payload Description:

- Nominal one-year mission, will collect > 16 billion vertical profile waveform observations
- 3 laser system to produce 14 parallel track measurements with 25 m footprints
- Mounted on Japanese Experiment Module Exposed Facility



Science Questions:

- What is the aboveground carbon balance of the land surface?
- What role will the land surface play in mitigating atmospheric CO₂ in the coming decades?
- How does ecosystem structure affect habitat quality and biodiversity?

Science Objectives:

- Quantify the distribution of above-ground carbon at fine spatial resolution
- Quantify changes in carbon resulting from disturbance and subsequent recovery
- Quantify the spatial and temporal distribution of forest structure and its relationship to habitat quality and biodiversity
- Quantify the sequestration potential of forests through time under changing land use and climate.

Total and Spectral Solar Irradiance Sensor (TSIS)

Description: Mounted on the ExPRESS

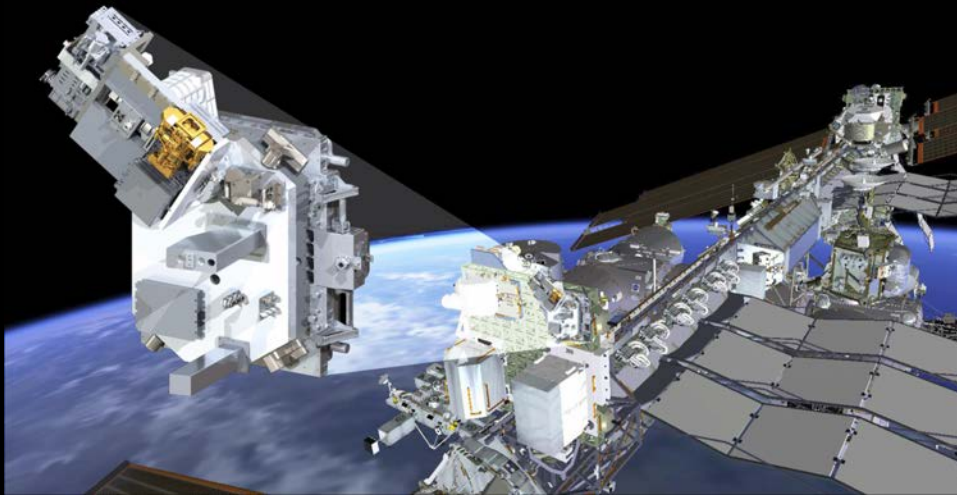
Logistics Carrier 3 (ELC-3), TSIS will acquire measurements of total and spectral solar irradiance (TSI and SSI, respectively). TSI is required for establishing Earth's total energy input while SSI is needed to understand how the atmosphere responds to changes in the sun's output. Solar irradiance is one of the longest and most fundamental of all climate data records derived from space-based observations.

Payload Description:

- Dual-instrument package of Total Irradiance Monitor (TIM) and Spectral Irradiance Monitor (SIM), both heritage instruments from NASA Solar Radiation and Climate Experiment (SORCE)
- TIM measures TSI incident at outer boundaries of atmosphere
- SIM measures SSI from 200 – 2400 nm (96% of TSI)

Science Objectives:

- Nominal five-year mission, provides continuation of TSI record from SORCE and USAF STPSat-3
- Quantify variability in incoming solar radiation, as the most precise indicator for changes in Sun's energy output
- Determine regions/layers of Earth's atmosphere that are affected by solar variability, in order to quantify solar forcing mechanisms causing changes in climate
- Determination of whether the Sun's spectral ultraviolet output is in- or out-of-phase with visible wavelength output
- Provision of TSI and SSI data to support community science in climate, atmosphere, solar physics, and radiative transfer modeling



Other USOS Sensor Systems & Capabilities relevant to Earth Science



Internal

NHK 4K Camera [2013] – super-sensitive 4K camera system, Kibo (JAXA)

External

High Definition Earth Viewing (HDEV) [2014] – four-camera fixed system (fore, aft, and nadir) for collecting HD imagery of Earth and monitoring exposure degradation, Columbus EF

NanoRacks External Platform (NREP) [2016] – pointable, stable platform for Earth-viewing instruments and technology tests, ELC. Four users of the platform were announced in August 2015:

- Gumstix/Solar Cells (Yosemite Space) radiation effects on System on Chip (SoC) processors
- Charge Injection Device (CID, Florida Institute of Technology) high contrast imaging technology test in low Earth orbit radiation
- A-76 Technologies –test of preservation coatings and lubricants in the high stress space environment
- Dependable Multiprocessing (DM7, Honeywell Aerospace/Morehead State University- DM7 processor test for CubeSat technology

Multi-User System for Earth Viewing (MUSES) [2016] – pointable, stable platform for Earth-viewing instruments, ELC; additional capabilities beyond DESIS available

Atmosphere-Space Interactions Monitor (ASIM) [2017] measure high altitude lightning that is discharged from thunderclouds, at altitudes of 90-100 km. These formations of lightning are known as "red sprites", "blue jets", and "elves" (ESA)

GNSS Reflectometry, Radio Occultation and Scatterometry on ISS (GEROS-ISS) [2019] – sea surface roughness and wind speed from navigation satellite data (ESA)

DLR Earth Sensing Imaging Spectrometer (DESI)

Description: Commercial hyperspectral instrument to be installed on the Teledyne-Brown Engineering Multi-User System for Earth Sensing (MUSES) platform for ISS. The instrument is being built by DLR (Deutsches Zentrum für Luft- und Raumfahrt e.V.; German Aerospace Center).

Details of the final sensor configuration and commercial user data pricing structure are still being finalized.



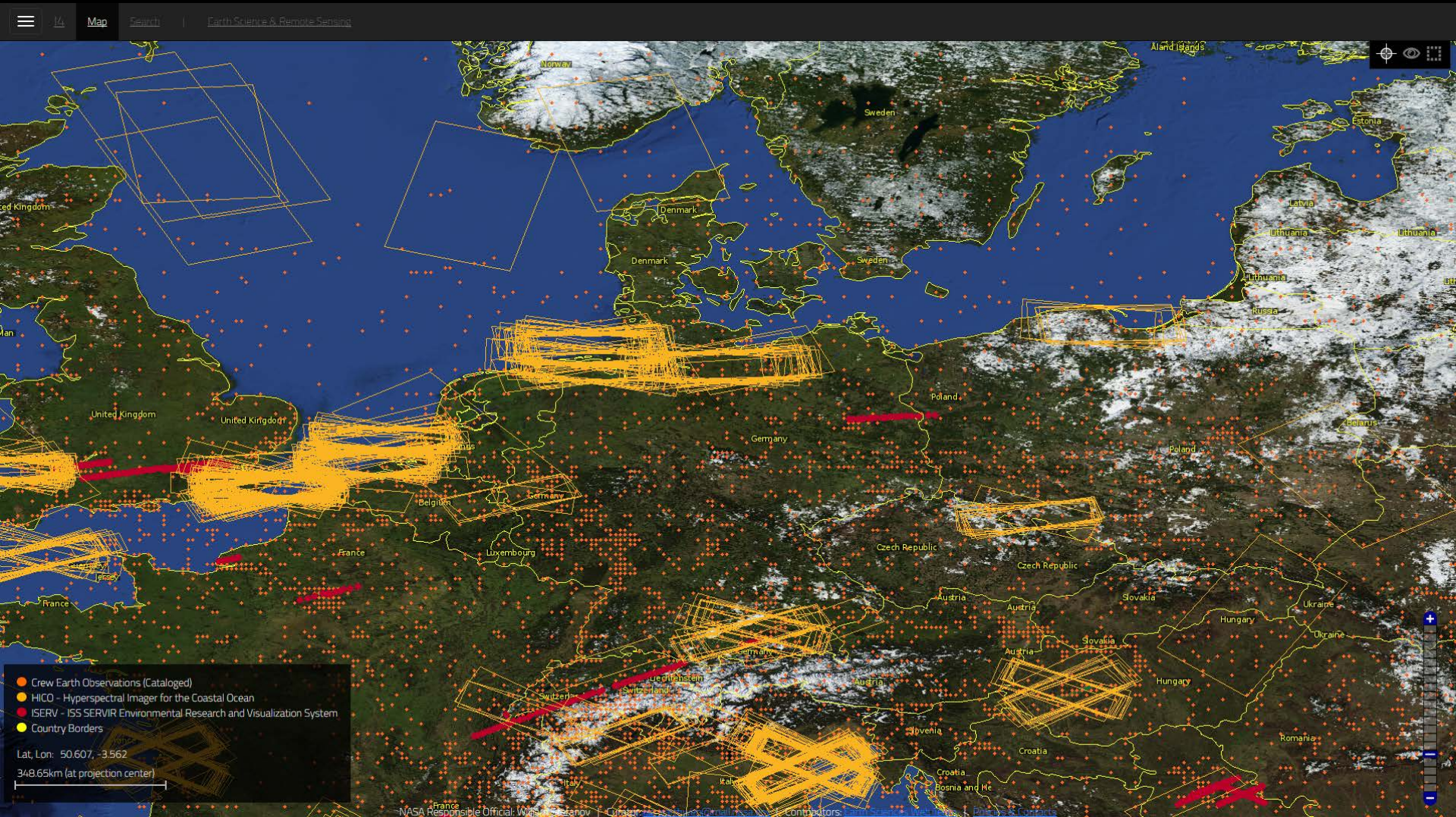
Lens objective	F# = 4 / f = 100mm (telecentric)
FOV / swath	7.6° / 44km/57km
IFOV / GSD	0.0074° / 79m/104m
Spectral range	450nm – 950nm (400 - 1000nm)
Spectral sampling	≈ 2,32nm
Spectral channels	240 (without binning)
Polarization sensitivity	≤ 0,3%
Size	430 mm × 190 mm × 135 mm
In orbit calibration	2 internal lamps, LED screen
Pointing (along-track)	± 15°

Example Markets/Research Areas:

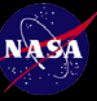
- Agriculture
- Atmospheric Studies
- Maritime Awareness
- Surface Mineralogy and Resource Assessment
- Forestry
- Ocean Studies
- Urban Ecology, Climatology, and Planning
- Water Quality Studies



14 Search Tool for ISS Earth Obs Data



<http://issearchserv.jsc.nasa.gov>



International Charter "Space and Major Disasters"

The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users. Each member agency has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property.



Member Agencies:

Americas



Europe

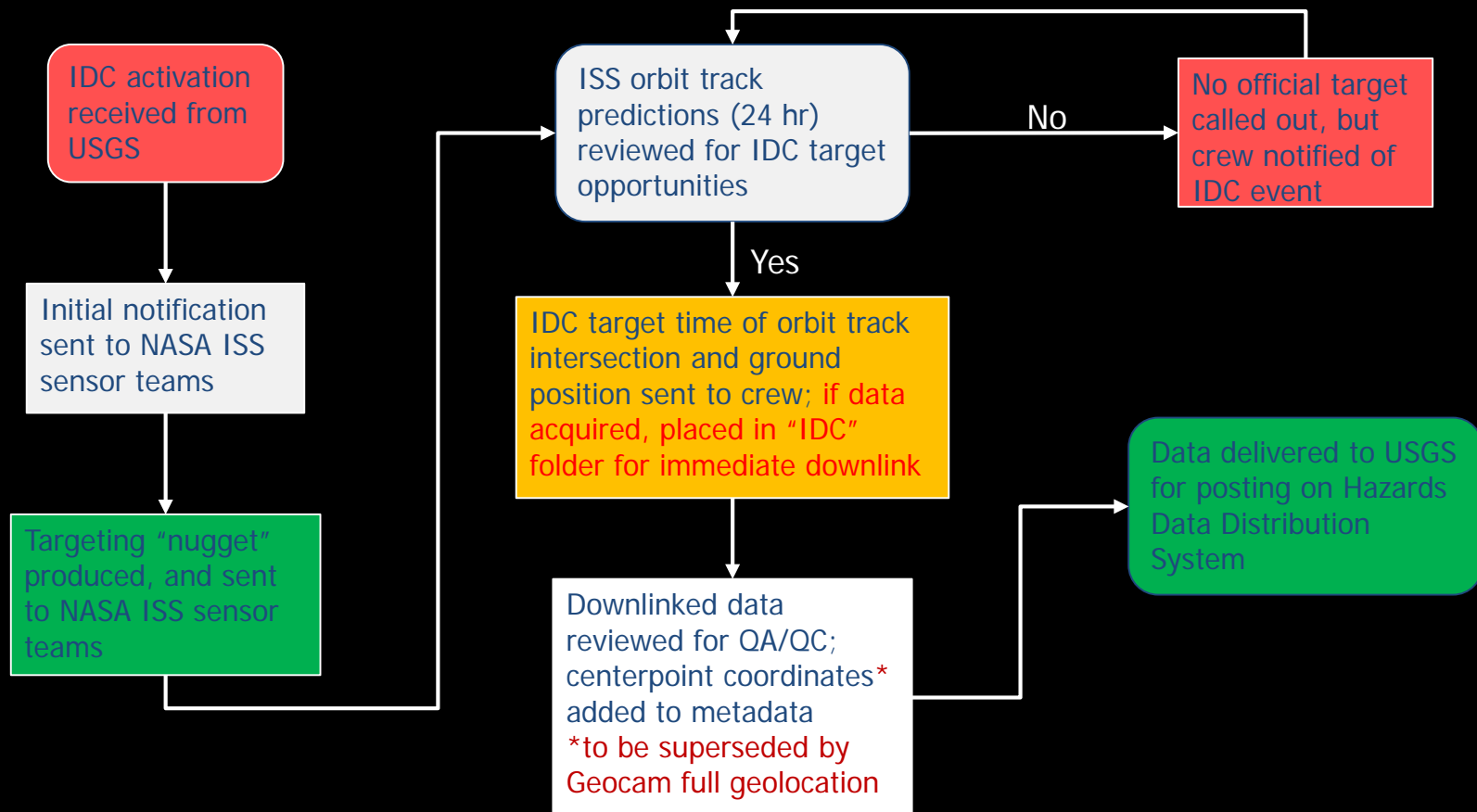


Asia





NASA ISS Disaster Charter Response (CEO)



Since late April/early May 2012, ISS has received 154 IDC activations; data collected for 43 events and delivered to USGS (ISSAC, CEO, HICO, ISERV)

<p>Site Plan Information</p> <p>Site objective: Document any visible evidence of the recent earthquake in Nepal and north-central India with special attention to urban areas like Kathmandu and to infrastructure such as roads and bridges.</p> <p>Window: Any available</p> <p>Lens: 50-180mm oblique, 400-1200mm near nadir</p> <p>Viewing angle: Near Vertical, Oblique</p> <p>Season: 25APR15 through 05MAY15</p> <p>Maximum clouds: 50%</p> <p>Frequency: As visible</p>	<p>Nugget</p> <p>A 7.9 magnitude earthquake struck Nepal at GMT 115 at 11:56 (local time). The epicenter of the earthquake was in central Nepal at 28 degree north latitude and 84 degrees east longitude. It has been described as the worst disaster to affect Nepal in 80 years. Some remote villages and towns in the region have been entirely buried by landslides. The capital city of Kathmandu, 80 km away from the epicenter also was effected with several locations of historical importance in the city suffering severe damage. Northern India, which borders Nepal, suffered damage in the earthquake with the states of Bihar and Sikkim particularly affected. The earthquake also caused avalanches on Mount Everest which left hundreds of mountain climbers stranded on the mountain when they lost their climbing gear in the avalanches.</p>
<p>Sized Reference Map</p>	<p>Recommended Site Coordinates:</p> <p>Type: Box</p> <p>Coordinates:</p> <ul style="list-style-type: none"> 28.6N 79.6E 27.1N 83.7E 24.3N 83.0E 24.3N 87.8E 28.1N 89.3E 28.2N 86.2E 30.9N 81.1E

Example of IDC targeting “nugget” delivered to NASA ISS sensor teams to aid in data collection



USGS Hazards Data Distribution System



USGS Home
Contact USGS
Search USGS

Hazards Data Distribution System (HDDS) Explorer

Page Expires In 1:57:56

Home Login Register RSS Feedback Help

Search Criteria Events Additional Criteria **Results**

4. Search Results



If you selected more than one event to search, use the dropdown to see the search results for each specific event.

Note: You must be logged in to download and order scenes

Show Result Controls

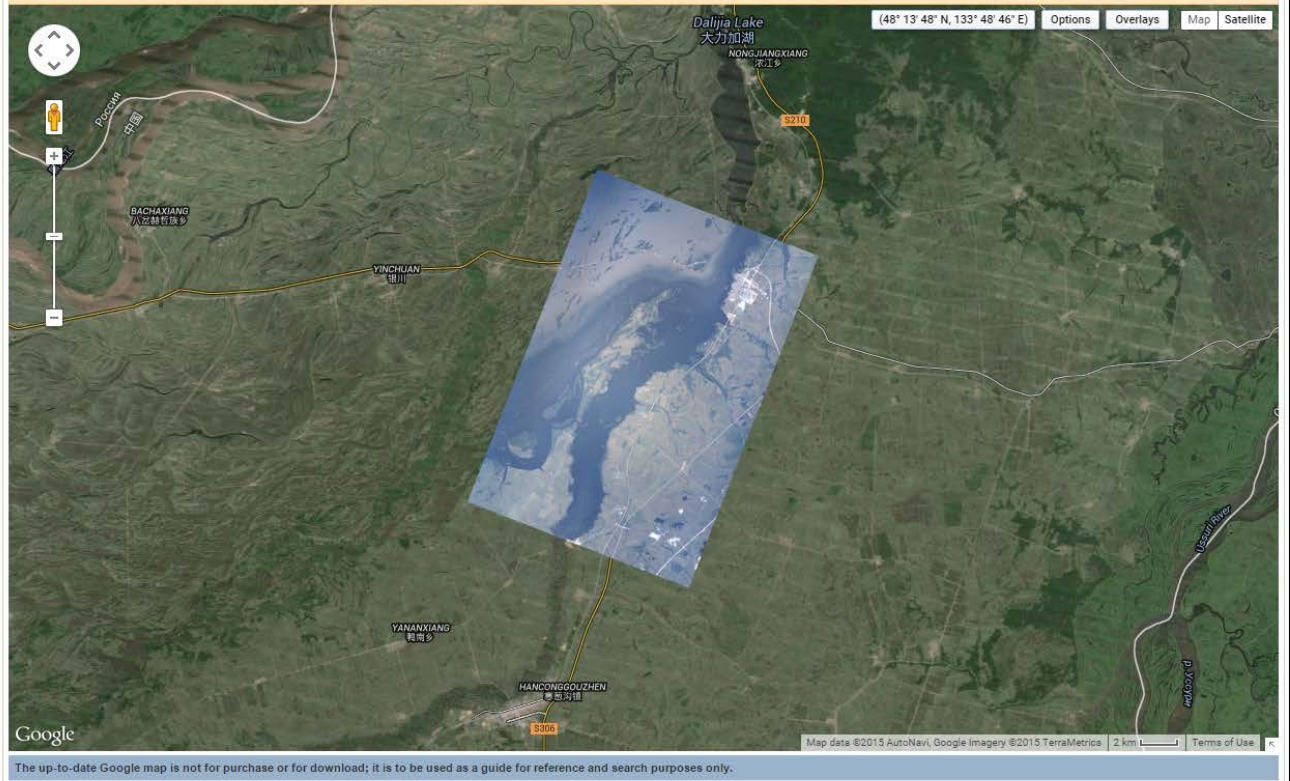
Event [Click here to export your results »](#)

201309_Floods_Russia

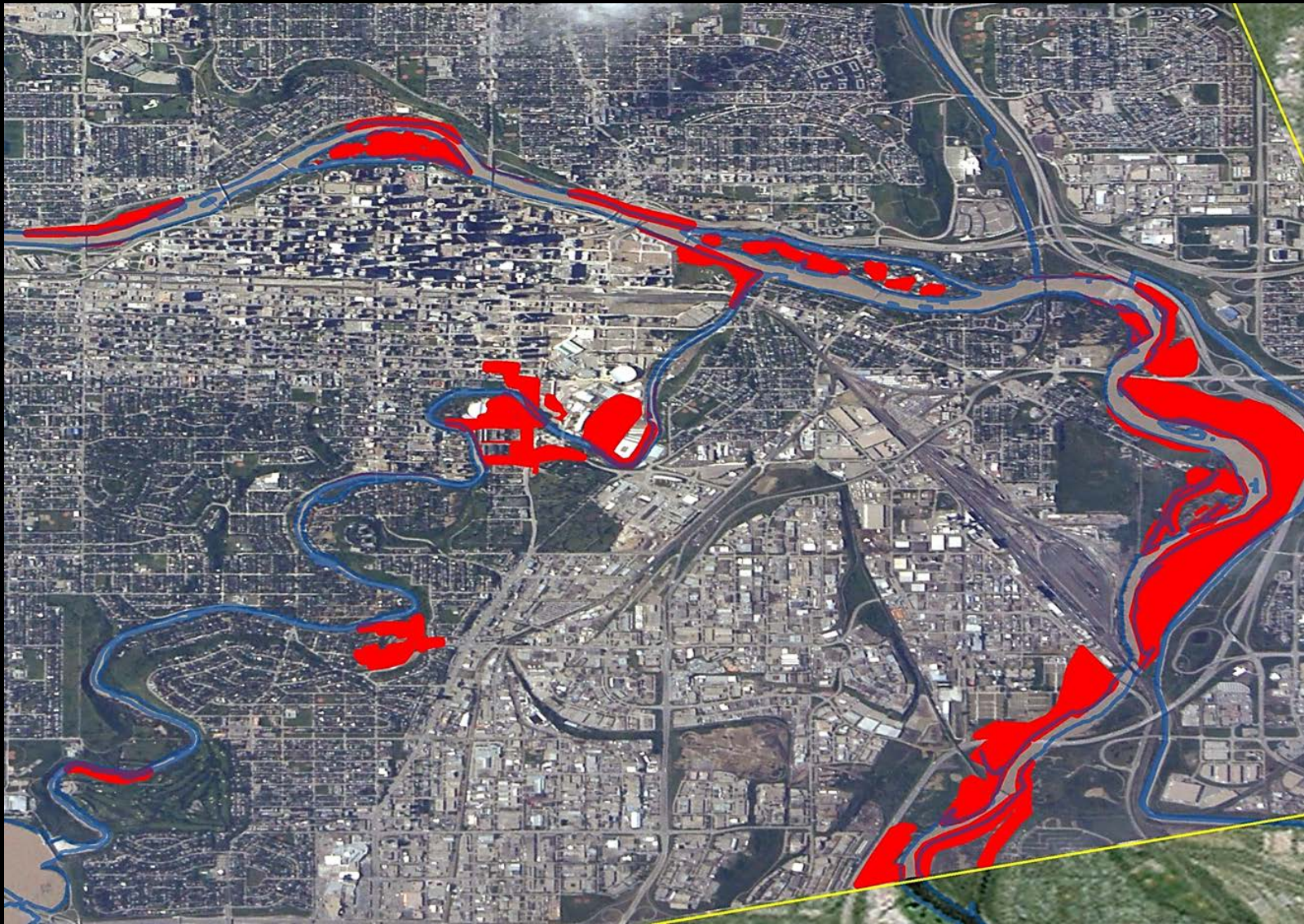
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Sensor: CAMERA
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Agency: NASA
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Platform: ISS 1
Sensor: CAMERA
Agency: NASA
File Format: GEOTIFF

Search Criteria Summary (Show)

Clear Criteria



<http://hddsexplorer.usgs.gov/>



ISERV – Calgary Flood, June 2013

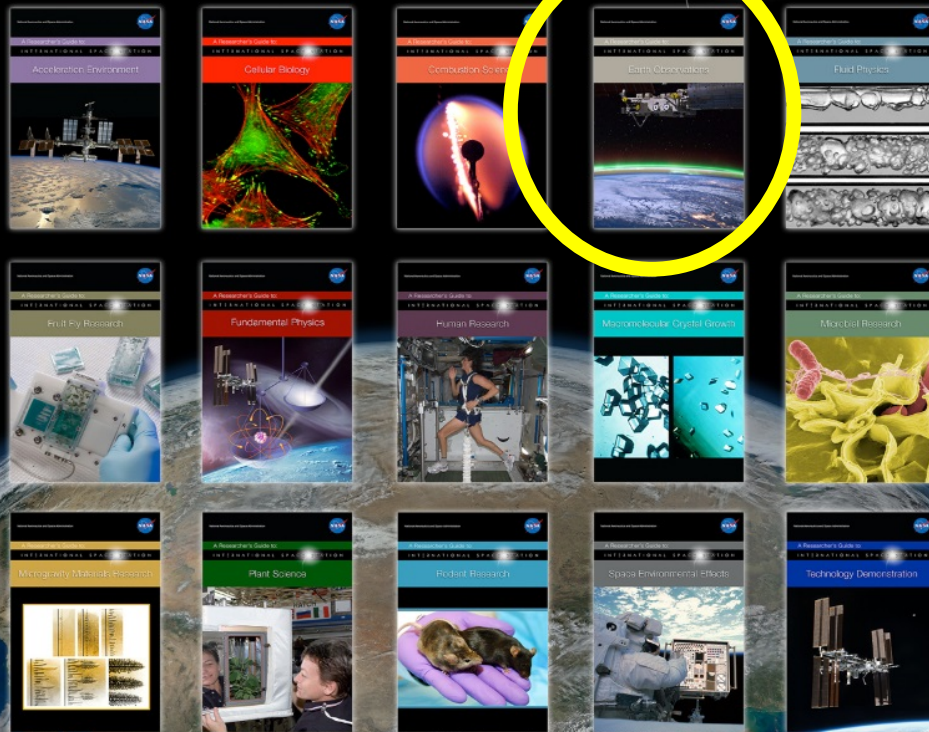
- 140 images taken to support mapping of flooded areas (red)
- Images given to Royal Canadian Mounted Police and other agencies for disaster response

National Aeronautics and Space Administration



INTERNATIONAL SPACE STATION

Researcher's Guide Series



Guide to Earth Observation on ISS

Available for download at

http://www.nasa.gov/mission_pages/station/research/ops/research_information.html

Existing facilities and instruments:

http://www.nasa.gov/mission_page/s/station/research/facilities_category/index.html



ISS Research & Technology
<http://www.nasa.gov/iss-science/>



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ISS Research Blog "A Lab Aloft"
<http://go.usa.gov/atI>



Space Station Research Explorer
App for Apple and Android

- iPad



- Android





Thank you for your attention!

Questions or Comments?



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