Earth Science Research on the International Space Station

Committee on Earth Science and Applications from Space (CESAS)
Space Studies Board
National Academies of Science, Engineering, Medicine
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Remote sensing of Earth: Why ISS?

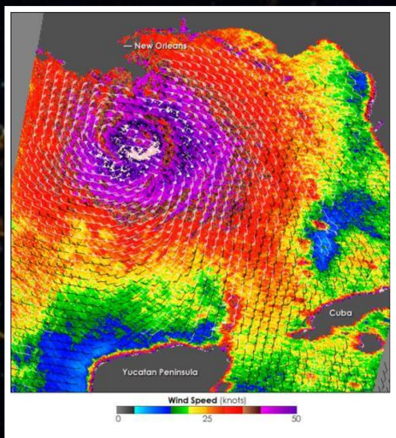
Polar orbit

- 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

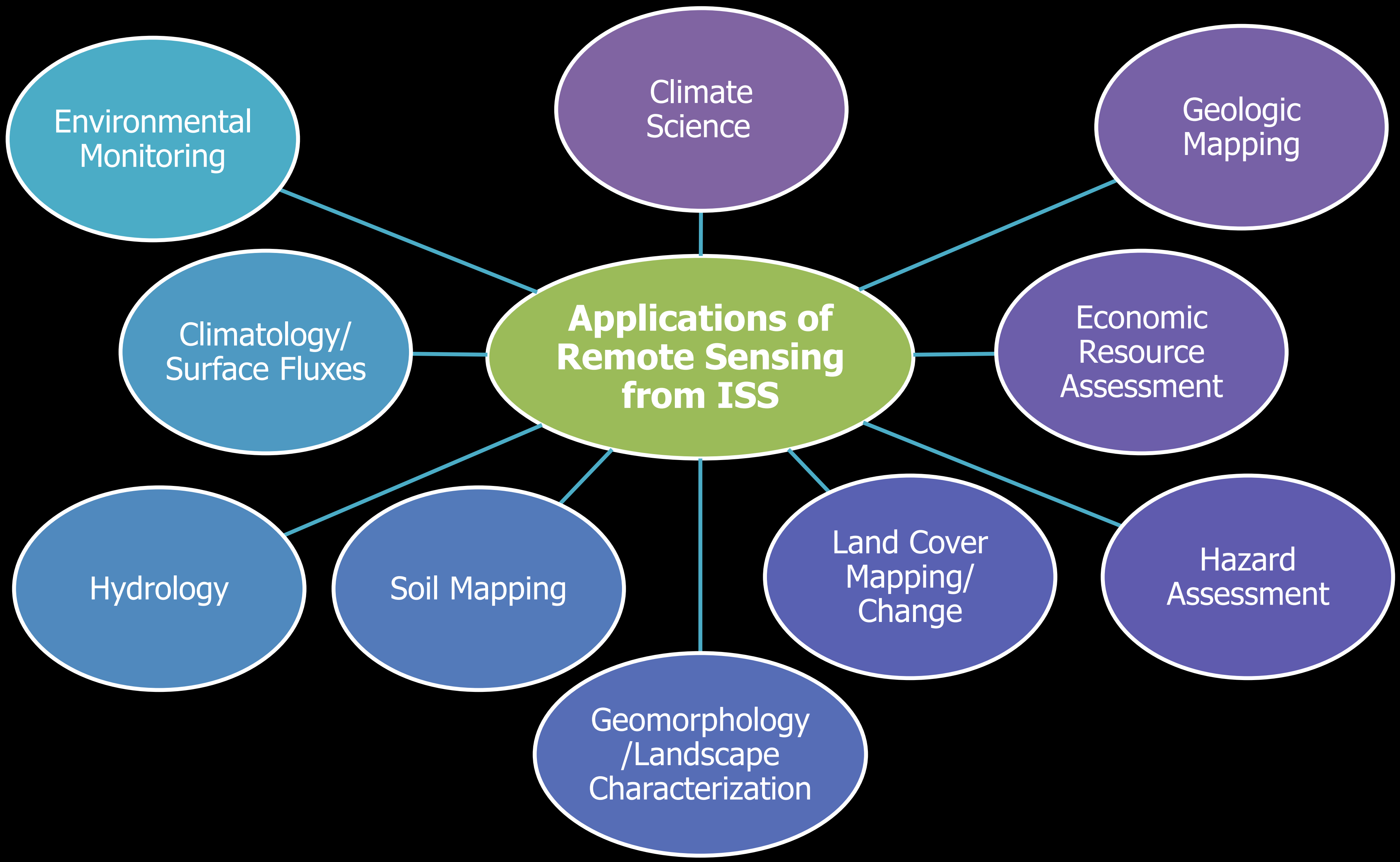
- Sun-asynchronous – similar illumination 3-4 days every 90 days
- Nadir to highly oblique imagery possible from hand-held cameras, WORF, external sensors
- Provides opportunity to collect unique datasets for scientific study, disaster response
- Data is complementary to polar-orbiting satellite data
- 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, two commercially developed platforms (NREP and MUSES) provided services for short-term testing of instrument, and include opportunities for NASA and non-NASA access

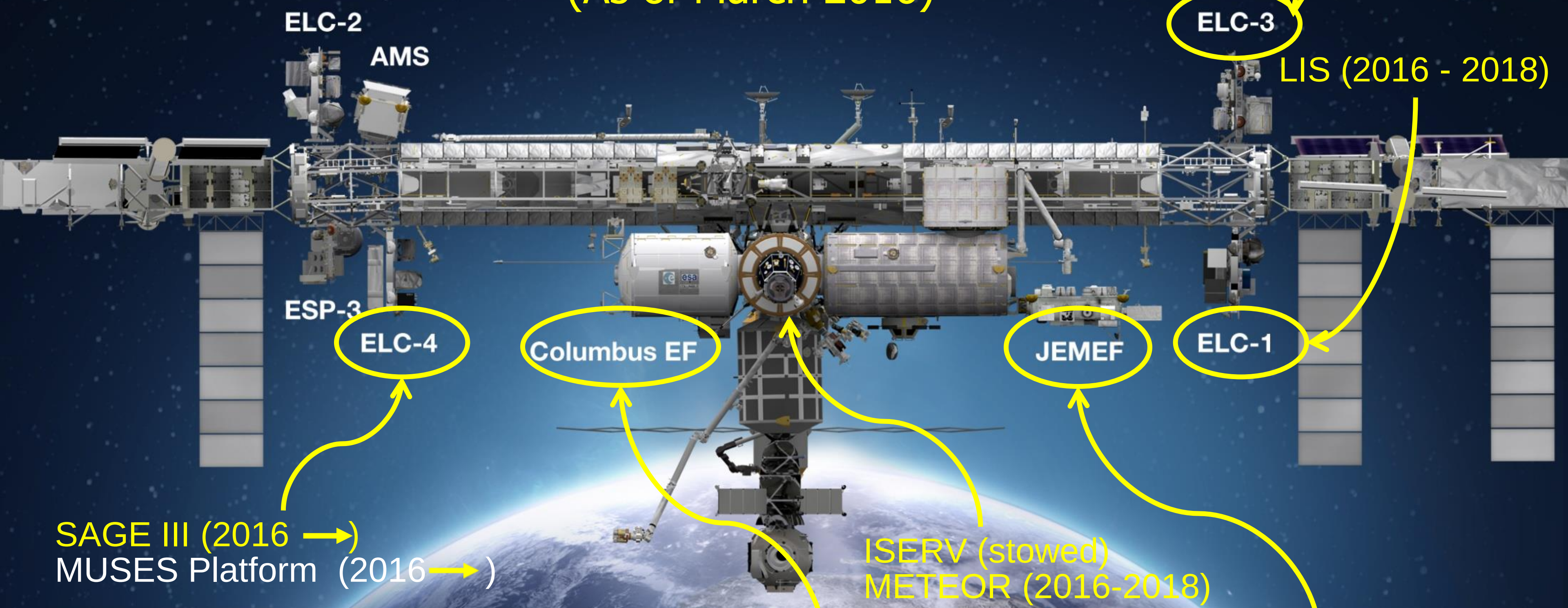
Applications of Remote Sensing from ISS



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

Information as of December 2015

WORKING PLAN

Multi-Increment Payload Resupply and Outfitting Model (MiPROM), as of 18 December 2015

NOTE: This is a strategic plan and subject to change

PAYLOAD READINESS DATE				2015		2016		2017		2018		2019		2020		2021		2022		2023		2024	
				2015-1	***2015-2***	***2016-1***	***2016-2***	***2017-1***	***2017-2***	***2018-1***	***2018-2***	***2019-1***	***2019-2***	***2020-1***	***2020-2***	***2021-1***	***2021-2***	***2022-1***	***2022-2***	***2023-1***	***2023-2***	***2024-1***	***2024-2***
				Oct-14	Apr-15	Oct-15	Apr-16	Oct-16	Apr-17	Oct-17	Apr-18	Oct-18	Apr-19	Oct-19	Apr-20	Oct-20	Apr-21	Oct-21	Apr-22	Oct-22	Apr-23	Oct-23	Apr-24
Carrier	**Location**	**Site Number**		41/42	43/44	45/46	47/48	49/50	51/52	53/54	55/56	57/58	59/60	61/62	63/64	65/66	67/68	69/70	71/72	73/74	75/76	77/78	79/80
ELC 1	P3 Lower	3	Outboard / Ram / Nadir	{STP-H4} [8]	{STP-H4}	{STP-H4} ↓	ROSA ↑ (NASA)	ROSA ↓	RRM3 *(NASA)*	RRM3	RRM3	RRM3	RRM3	TBR	TBR	TBR	TBR	TBR	TBR				
ELC 1	P3 Lower	8	Inboard / Wake /Nadir	OPALS [1]	{OPALS}	OPALS ↓ -------- STP-H5 ↑ *(NASA)*	STP-H5	STP-H5	STP-H5	STP-H5				TBR	TBR	TBR	TBR	TBR	TBR	TBR	TBR	TBR	TBR
ELC 4	S3 Lower Inboard	2	Inboard / Wake / Nadir	[MUSES] *(NASA)*	[MUSES]	[MUSES]	MUSES ↑	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES	MUSES
ELC 4	S3 Lower Inboard	3	Inboard / Ram / Nadir	RRM [1]	RRM	RRM [8] ↓ --------- [SAGE NVP] [8] ↑ *(NASA)* ---------- [SAGE III/Hexapod] [8] ↑ *(NASA)*	SAGE III	SAGE III	SAGE III	SAGE III	SAGE III	SAGE III	SAGE III	SAGE III	SAGE III	{SAGE III} [11]	{SAGE III}	{SAGE III}	{SAGE III}	{SAGE III}	{SAGE III}	{SAGE III}	{SAGE III}
ELC 2	S3 Upper Outboard	3	Inboard / Ram / Zenith	MISSE 8 [1]	MISSE 8	MISSE 8	MISSE 8 [12] ↓		[MISSE-FF] *(NASA)*	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF	MISSE-FF
ELC 2	S3 Upper Outboard	7	Outboard / Ram / Zenith				NICER ↑ (NASA)	NICER	NICER	NICER	NICER	{NICER} [11]	{NICER}	{NICER}	{NICER}	{NICER}	{NICER}	TBR	TBR	TBR	TBR		
ELC 3	P3 Upper	3	Inboard / Ram / Zenith	SCAN Testbed [1]	SCAN Testbed	SCAN Testbed	SCAN Testbed	SCAN Testbed	SCAN Testbed	SCAN Testbed	SCAN Testbed	[STP-H6] *(NASA)*	STP-H6	STP-H6	STP-H6	{STP-H6}	TBR	TBR	TBR	TBR	TBR	TBR	TBR
ELC 3	P3 Upper	5	Outboard / Wake / Zenith						TSIS ↑ *(NASA)*	TSIS	TSIS	TSIS	TSIS	TSIS	TSIS	TSIS	TSIS	TSIS					
Columbus	EPF SOZ		Overhead / Zenith	SOLAR [1]	SOLAR	SOLAR	SOLAR	SOLAR	SOLAR	SOLAR	SOLAR	SOLAR	SOLAR	SOLAR	SOLAR	TBR	TBR	TBR	TBR				
Columbus	EPF SOX		Overhead / Ram				[SDS] *(NASA)*	SDS ↑	SDS	SDS	SDS	SDS	GEROS *(ESA)*	GEROS	GEROS	TBR	TBR	TBR	TBR				
Columbus	EPF SDX		Deck / Ram	RapidScat ↑ *(NASA)* ---------- Adapter Bracket ↑ *(NASA)*	RapidScat	{RapidScat }	{RapidScat}	{RapidScat} ↓ {Adapt. Bracket} ↓ -------- ASIM ↑ *(NASA launch; ESA ops)*	ASIM	ASIM	ASIM	ASIM	ASIM	ASIM	ASIM	TBR	TBR	TBR	TBR				
Columbus	EPF SDN		Deck / Nadir	HDEV [1]	HDEV	HDEV	HDEV	HDEV ↓ -------- ACES ↑ *(NASA launch; ESA ops)*	ACES	ACES	ACES	ACES	ACES	ACES	ACES	TBR	TBR	TBR	TBR				
JEM-EF		1	Ram/ Nadir/ Zenith	MAXI [1]	MAXI	MAXI	MAXI	MAXI	MAXI	MAXI	MAXI	MAXI	MAXI	TBD J-3	TBD J-3	TBR	TBR	TBR	TBR	TBR	TBR	TBR	TBR
JEM-EF		3	Ram/ Nadir/ Zenith	CATS ↑ *(NASA)*	CATS	CATS	CATS	CATS	CATS	CATS	[OCO-3] *(NASA)*	OCO-3	OCO-3	OCO-3	OCO-3	OCO-3	{OCO-3}	TBR	TBR	TBR	TBR	TBR	TBR
JEM-EF		5	Ram/ Nadir/ Zenith	SMILES *(from J-3)*	SMILES ↓	EFU Adapter 1 6 *(GOJ)*	EFU Adapter 1	EFU Adapter 1	EFU Adapter 1	EFU Adapter 1	EFU Adapter 1	EFU Adapter 1	EFU Adapter 1	EFU Adapter 1	EFU Adapter 1	TBR	TBR	TBR	TBR	TBR	TBR	TBR	TBR
JEM-EF		7 [5]	Ram/ Nadir/ Zenith	ICS (System)									Next ICS (System)										
JEM-EF		9 [3]	Port/ Nadir/ Zenith	SEDA-AP [7] *(to J-11)*	CALET [8] ↑ *(GOJ)*	CALET	CALET	CALET	CALET	CALET	CALET	CALET	CALET	CALET [9]	CALET	TBR	TBR	TBR	TBR	TBR	TBR	TBR	TBR
JEM-EF		2	Wake/ Nadir/ Zenith							CREAM	{CREAM} [11]	{CREAM}	{CREAM}	{CREAM}	{CREAM}	TBR	TBR	TBR	TBR	TBR	TBR	TBR	TBR
JEM-EF		4	Wake/ Nadir/ Zenith							NREP	NREP	NREP	NREP	NREP	NREP	NREP	NREP	NREP	NREP	NREP	NREP	NREP	NREP
JEM-EF		6	Wake/ Nadir/ Zenith							{HREP}	GEDI Lidar *(NASA)*	GEDI Lidar	GEDI Lidar	{GEDI Lidar}	TBD J-4	TBR	TBR	TBR	TBR	TBR	TBR	TBR	TBR
JEM-EF		8	Wake/ Nadir/ Zenith							U Adapter 2	EFU Adapter 2	EFU Adapter 2	EFU Adapter 2	EFU Adapter 2	EFU Adapter 2	TBR	TBR	TBR	TBR	TBR	TBR	TBR	TBR
JEM-EF		*10*	*Wake/ Nadir/ Zenith*							COSTRESS	ECOSTRESS	{ECOSTRESS}											
JEM-EF		*11*	*Zenith*							EDA-AP	SEDA-AP ↓ [TBD] [2]	{SEDA-AP}	{SEDA-AP}	{SEDA-AP}	NASA-TBD-NL	NASA-TBD-NL	NASA-TBD-NL	NASA-TBD-NL	NASA-TBD-NL	NASA-TBD-NL	NASA-TBD-NL	NASA-TBD-NL	NASA-TBD-NL
JEM-EF		*12* [4]	*Zenith*													*Temp stowage location*							

LEGEND:
NASA payloads = no shading
JAXA payloads = orange
ESA payloads = purple
Candidate payloads = gray
Potential vacant sites = green

Working Unpressurized Launch Manifest as of March 2016

(Subject to change)

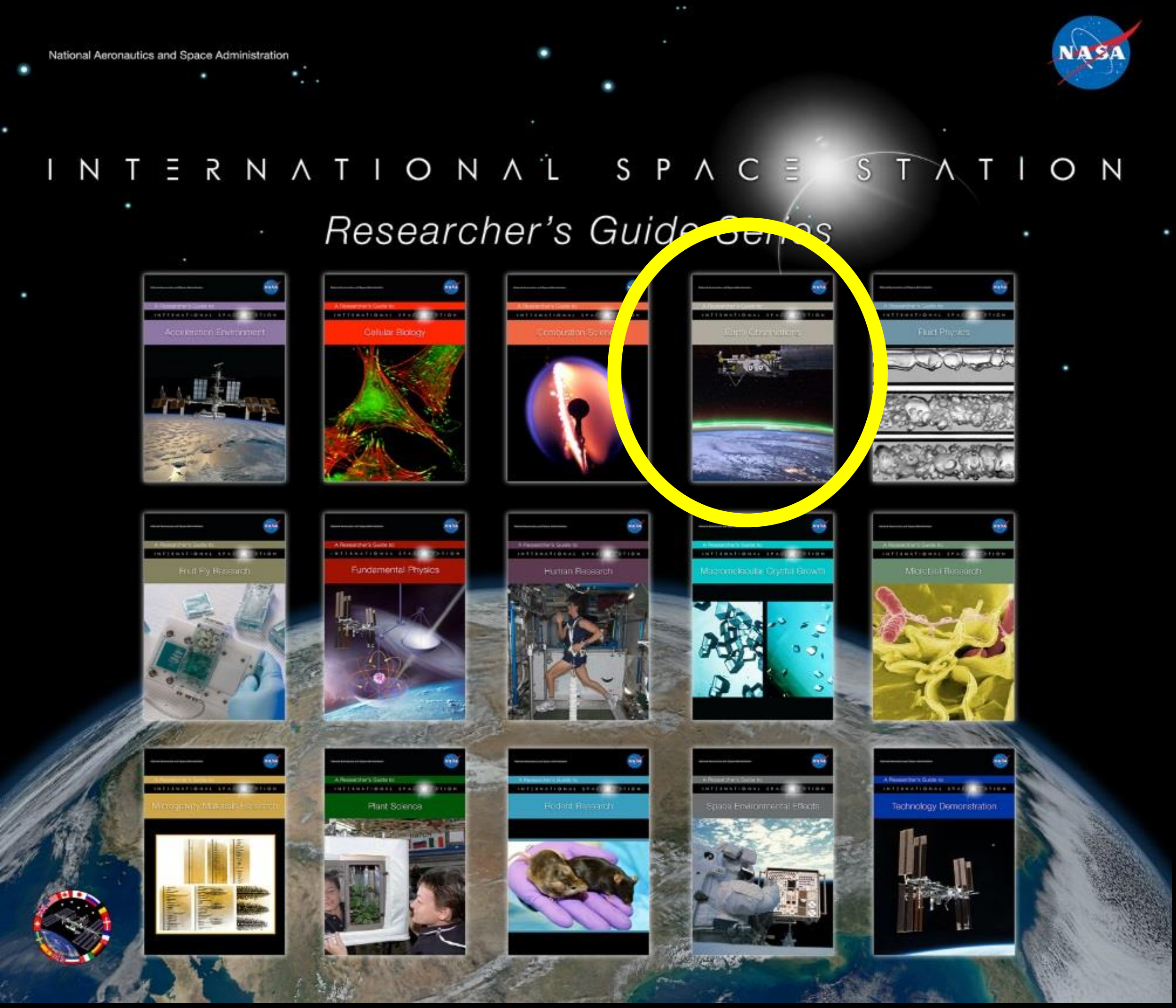
Earth Science

	Ascent			Descent		
SpX-8 *(early Apr 2016)*		*BEAM*				
SpX-9* *(24 Jun 2016)*		IDA #2				
SpX-10* *(1 Aug 2016)*	STP-H5 **(LIS)**	SAGE IP	SAGE NVP	OPALS	*RRM*	MISSE FSE
SpX-11* *(13 Jan 2017)*	**ROSA**	**MUSES** **Multi-user platform**	NICER	**ROSA** (nominal)		
SpX-12* *(6 Apr 2017)*		CREAM				
SpX-13* *(Aug 2017)*	ASIM	ACES	SDS	RAPIDSCAT (FRAM 1)	RAPIDSCAT (FRAM 2)	HDEV
SpX-14* *(Oct 2017)*		IDA #3				
SpX-15* *(Apr 2018)*	TSIS	**MISSE-FF**	RRM3 (FRAM 1)	**ROSA** (contingency)		
SpX-16* *(Jun 2018)*	ECOSTRESS (EF)	RRM3 (FRAM 2) TBR	*(not available)*	HREP (EF)		
SpX-17* *(Oct 2018)*	OCO-3 (EF)	**STP-H6**	*(not available)*	CATS (EF)	SCAN Testbed	
SpX-18* *(Jan 2019)*	GEDI (EF)		*(not available)*	SEDA-AP (EF) TBR		
SpX-19* *(May 2019)*		(Systems Placeholder)				
SpX-20* *(Jul 2019)*	**NASA-TBD-NL (EF) TBR**	GEROS	*(not available)*			

Key:
normal = NASA research
bold = **NL**
purple = ESA
orange = JAXA

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



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_pages/station/research/facilities_category/index.html

ISS Research & Technology

http://www.nasa.gov/iss-science/

@ISS_Research

ISS Research Blog “A Lab Aloft”

http://go.usa.gov/atI

Space Station Research Explorer

App for Apple and Android

- iPad
- Android

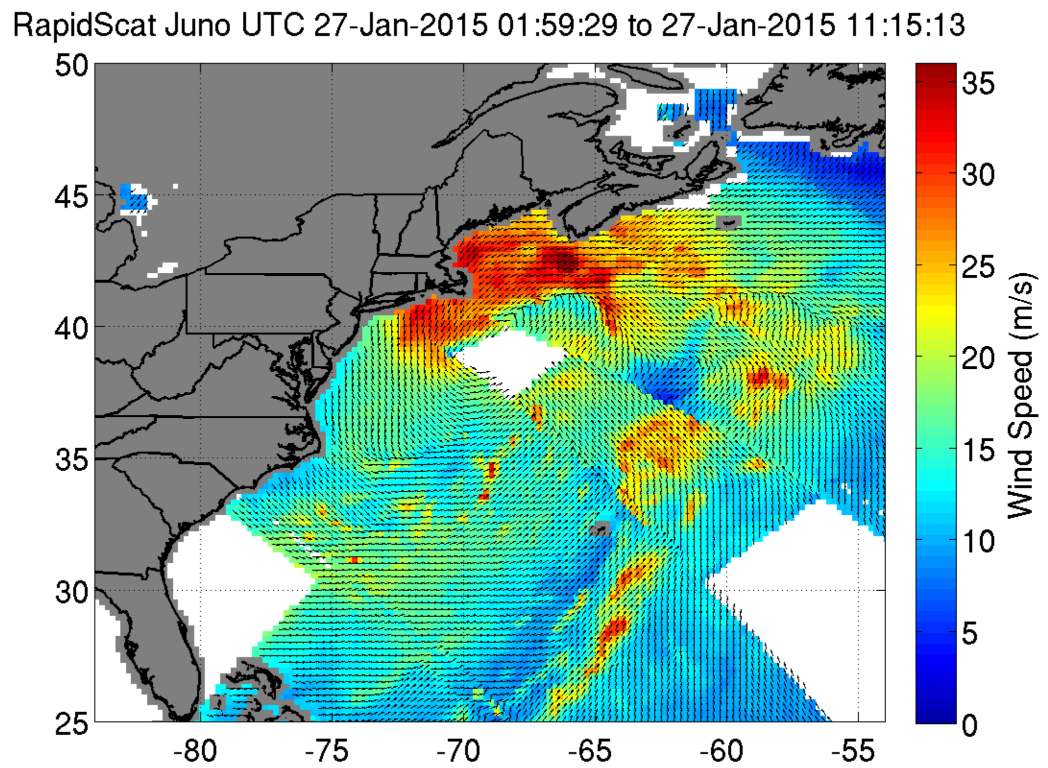
EXTERNAL INSTRUMENTS

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



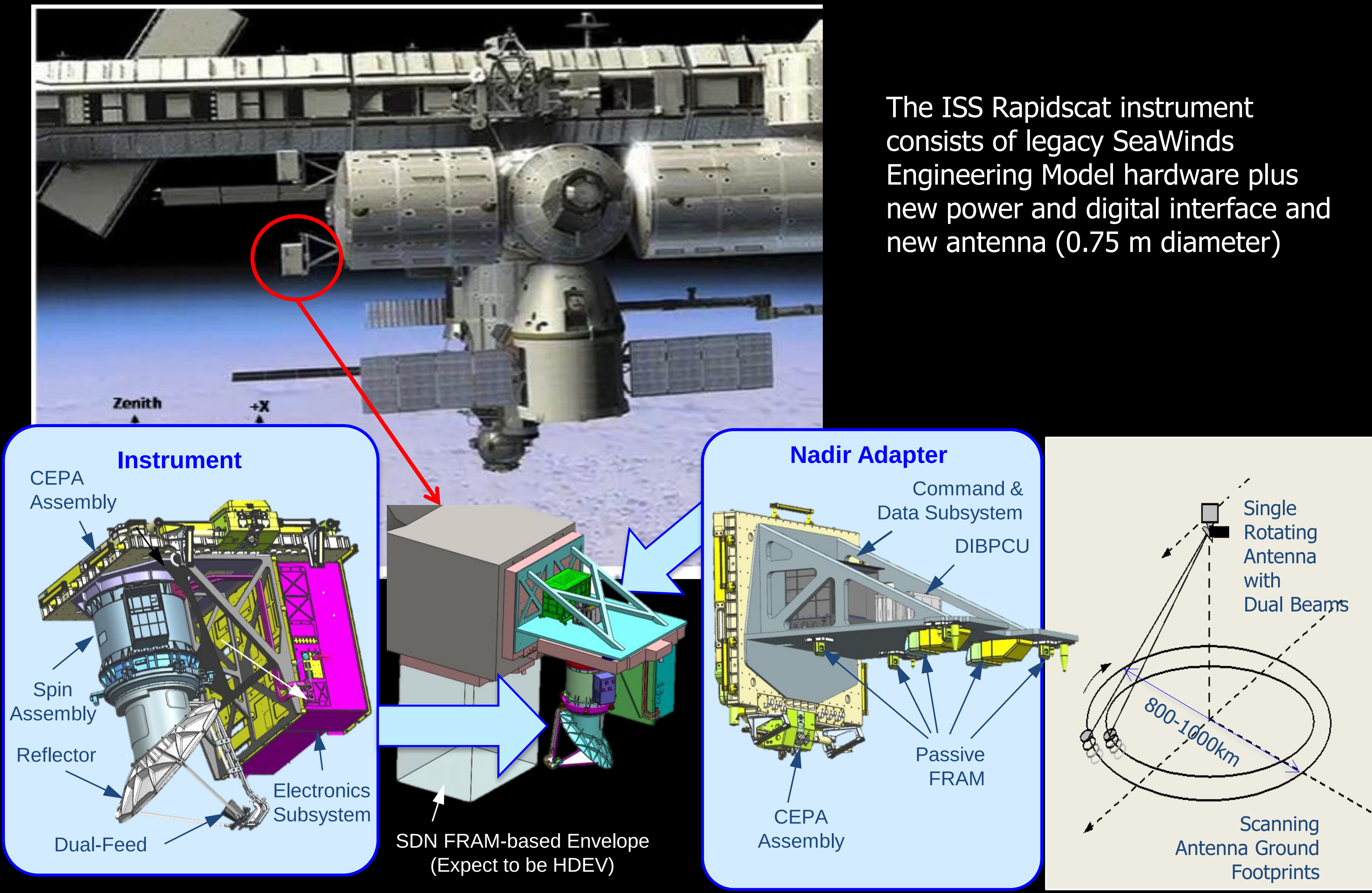
Source: http://cdn.phys.org/newman/gfx/news/hires/2015/1-nasameasured.png

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 ±52° latitude in 48 hrs
- Wind resolution comparable to QuikSCAT
- Mass: 200 kg, Power: 250 W; Data Rate: 40 kbps, continuous

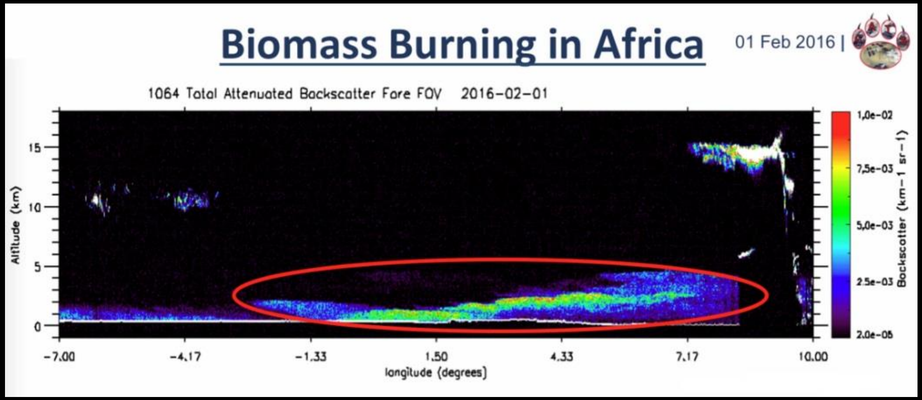
RapidScat Instrument

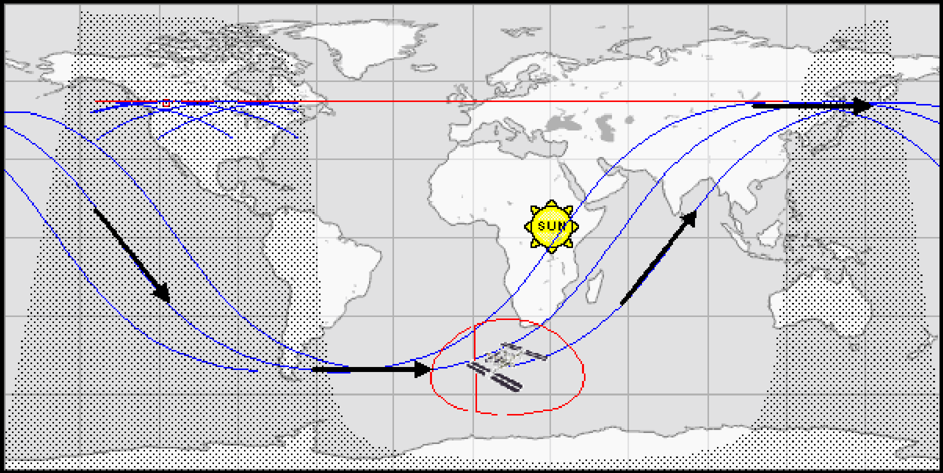
The ISS Rapidscat instrument consists of legacy SeaWinds Engineering Model hardware plus new power and digital interface and new antenna (0.75 m diameter)



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).



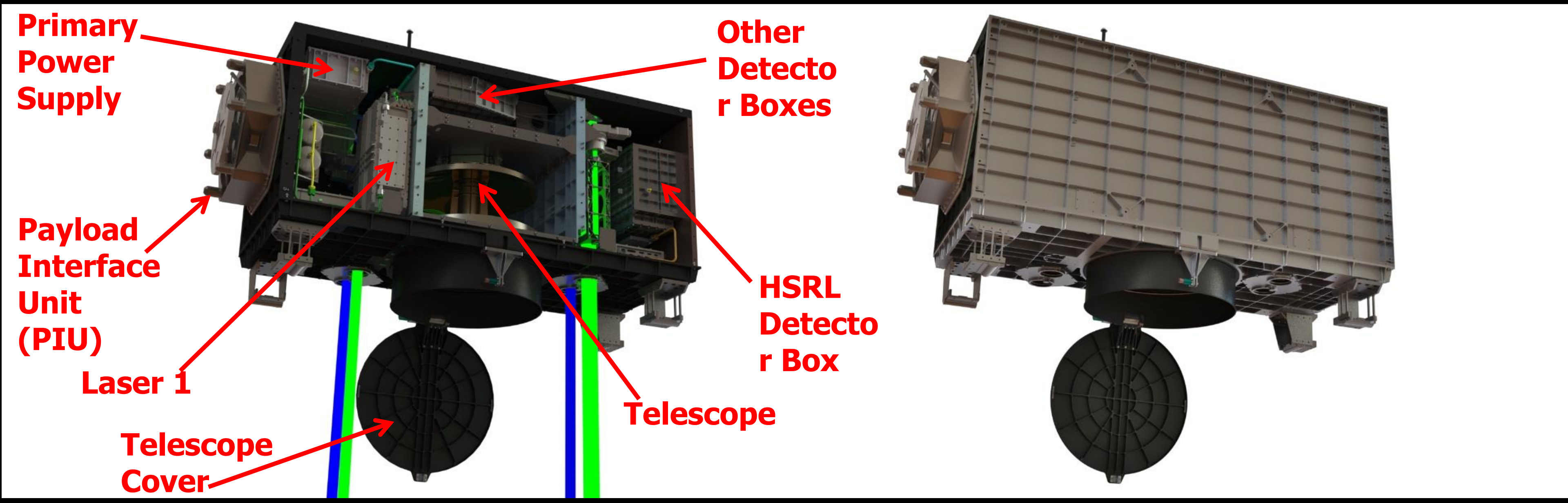


ISS orbit. The low-inclination orbit permits extensive measurements over aerosol source and aerosol transport regions.

CATS Instrument

- **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



DLR Earth Sensing Imaging Spectrometer (DESIS) on the MUSES Platform

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. NASA will receive a yet to be determined "credit value" for data takes, nominally distributed over the lifetime of the sensor. The licensing agreement for use and distribution of NASA data to science investigators is likewise still in discussion.

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°

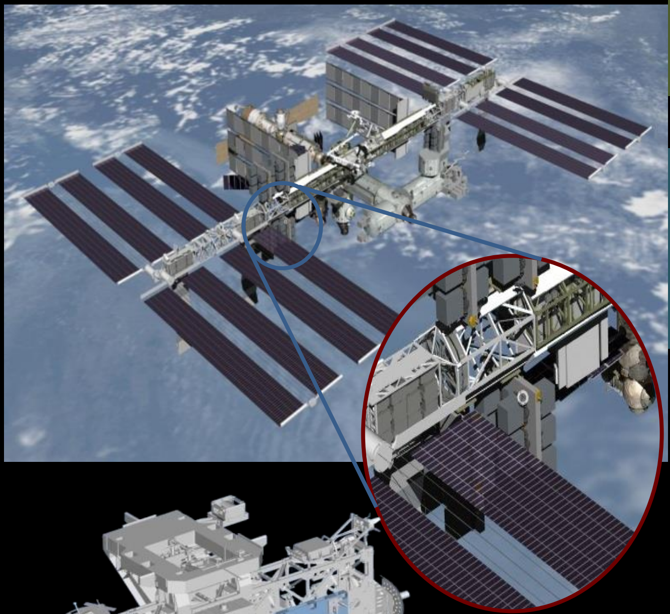
Example Markets/Research Areas:

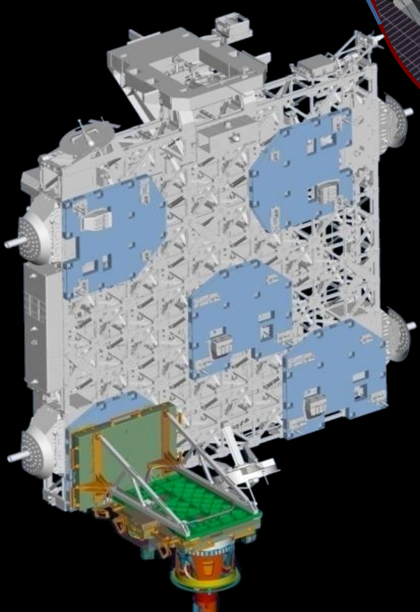
- Agriculture
- Atmospheric Studies
- Maritime Awareness
- Surface Mineralogy and Resource Assessment
- Forestry
- Ocean Studies
- Urban Ecology, Climatology, and Planning
- Water Quality Studies

http://www.dlr.de/os/en/desktopdefault.aspx/tabid-9294/16011_read-39367/

SAGE III on ISS
Project Description

www-sage3oniss.larc.nasa.gov





www-sage3oniss.larc.nasa.gov

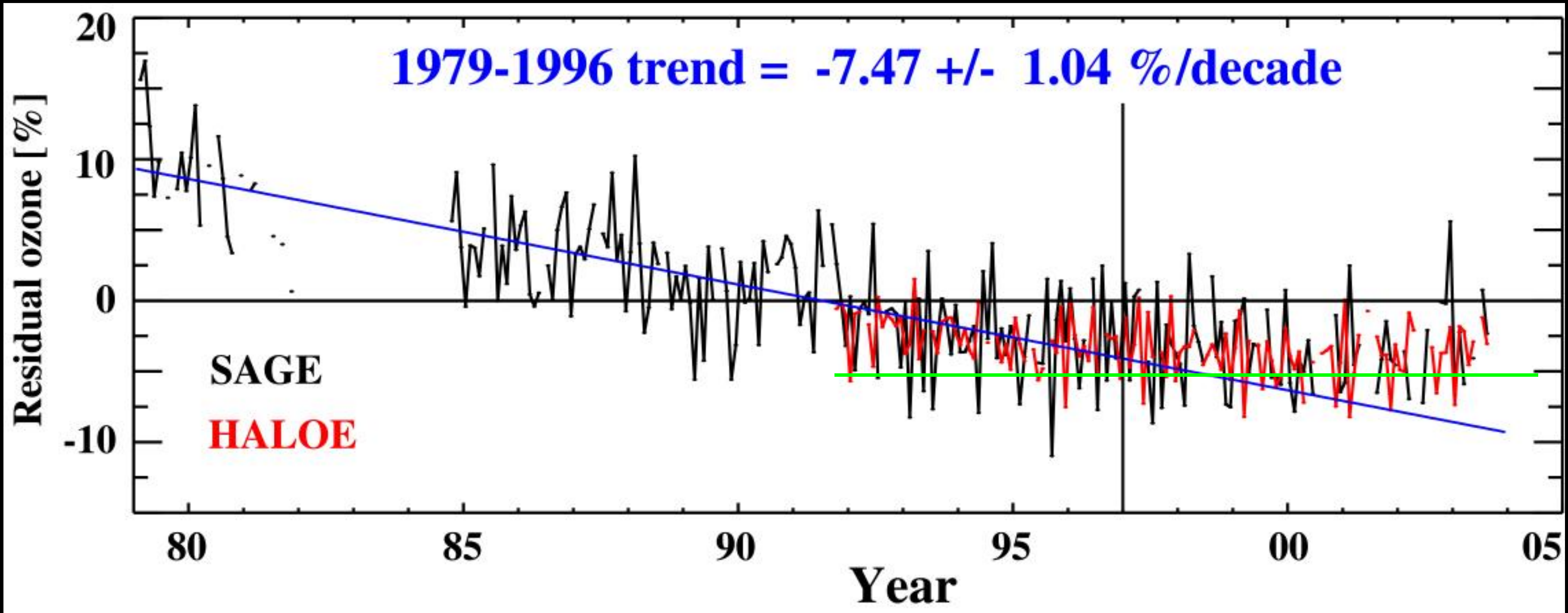
SAGE III on ISS directly supports NASA Strategic Goals to extend and sustain human activities across the solar system; expand scientific understanding of the Earth and the universe in which we live

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

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)

SAGE Science Results & Objectives

- SAGE produces vertical profiles of aerosols and gases in the stratosphere and upper troposphere
- The multi-decadal SAGE ozone and aerosol data sets have undergone intense scrutiny and are the international standard for accuracy and stability
- SAGE data has been used to monitor the effectiveness of the Montreal Protocol (January 1989)



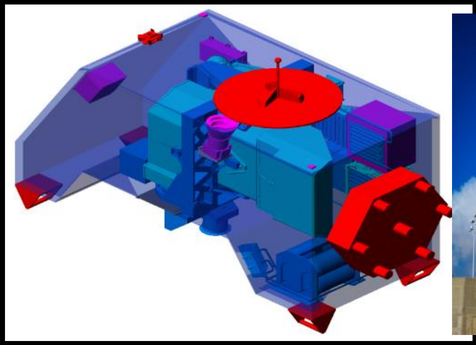
Orbiting Carbon Observatory (OCO-3) Project Overview

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_{CO2}, 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

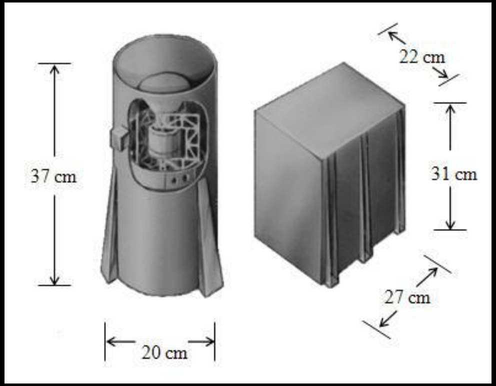
OCO-3 Requirements in Payload Interface Agreement	
Mass	500 kg
Power	600 W
Data Rate	3 Mbps
Volume	1.85 m x 1.0 m x 0.8 m
Thermal	Fluid Cooling Loop



Lightning Imaging Sensor (LIS) on ISS

Mission Overview

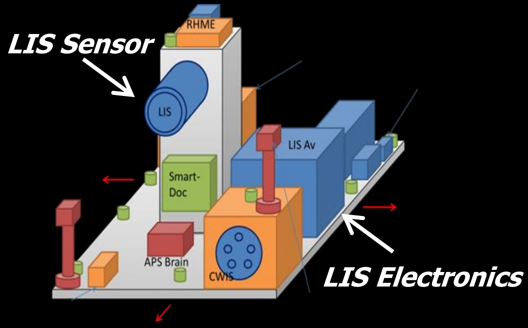
- NASA developed and demonstrated space-based lightning observation as a remote sensing tool under Earth Observing System (EOS) and Tropical Rainfall Measuring Mission (TRMM) (*LIS still operational on TRMM*).
- LIS on the ISS will extend TRMM time series observations, expand latitudinal coverage, and 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.



STP-H5 (notional concept)

Science and Application Objectives

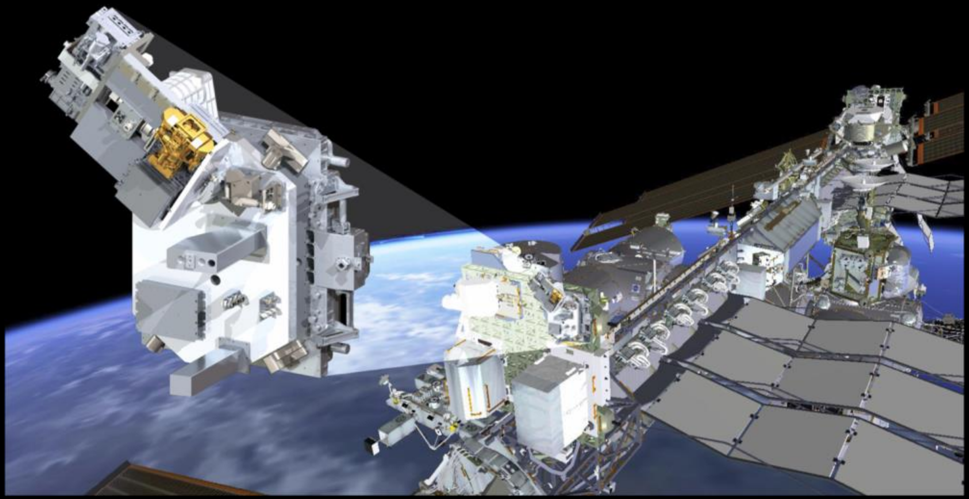
- Lightning is quantitatively coupled to both thunderstorm and related geophysical processes.
- Therefore lightning observations provide important gap-filling inputs to pressing Earth system sciences issues in a wide range of disciplines (e.g., *weather, climate, atmospheric chemistry, lightning physics*).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

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:

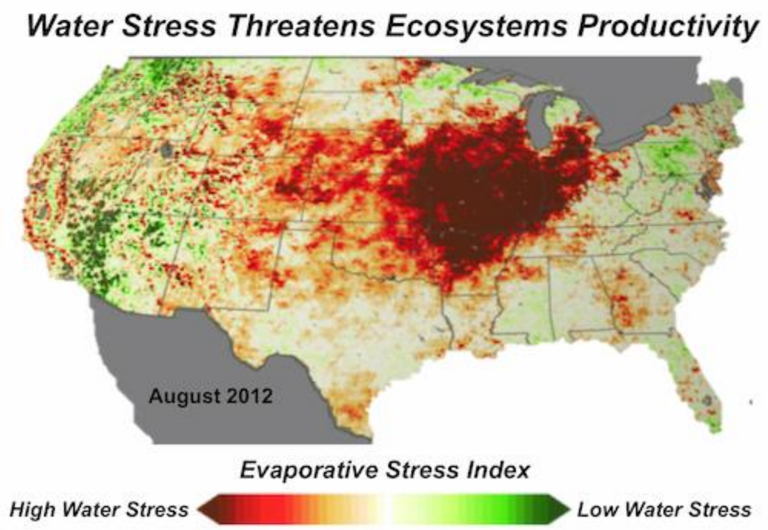
- Dual-instrument package of Total Irradiance Monitor (TIM) and Spectral Irradiance Monitor (SIM), both heritage instruments from NASA Solar Radiation and Climate Experiment (SORCE)
- TIM measures TSI incident at outer boundaries of atmosphere
- SIM measures SSI from 200 – 2400 nm (96% of TSI)



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

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:

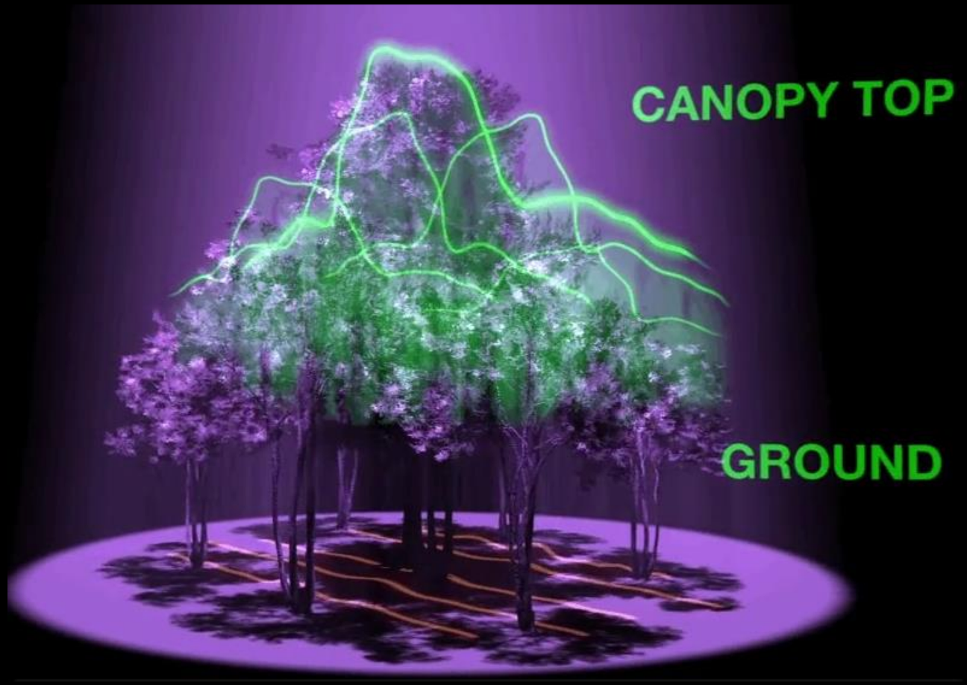
- Identify critical thresholds of water use and water stress in key climate sensitive biomes (e.g., tropical/dry transition forests, boreal forests);
- Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle;
- Measure agricultural 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 CO_2 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.

CREW EARTH OBSERVATIONS

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

Crew Earth Observations (CEO) – Upsala Glacier

2002
ISS004-E-6929 part

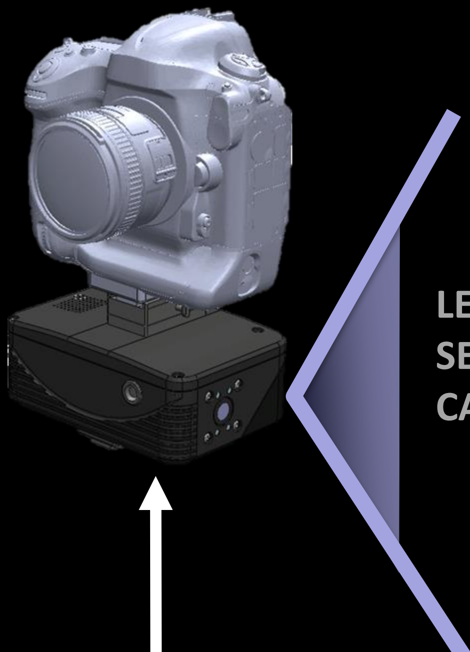
2009
ISS021-E-15242 part

2013, October 2
ISS037-E-5104 part

Slide courtesy of M.J. Wilkinson, Texas State University/JETS Contract, JSC

GeoCam Space System – late 2016/early 2017

GeoSens Hardware (NASA Ames)



LEFT-FACING SECONDARY CAMERA

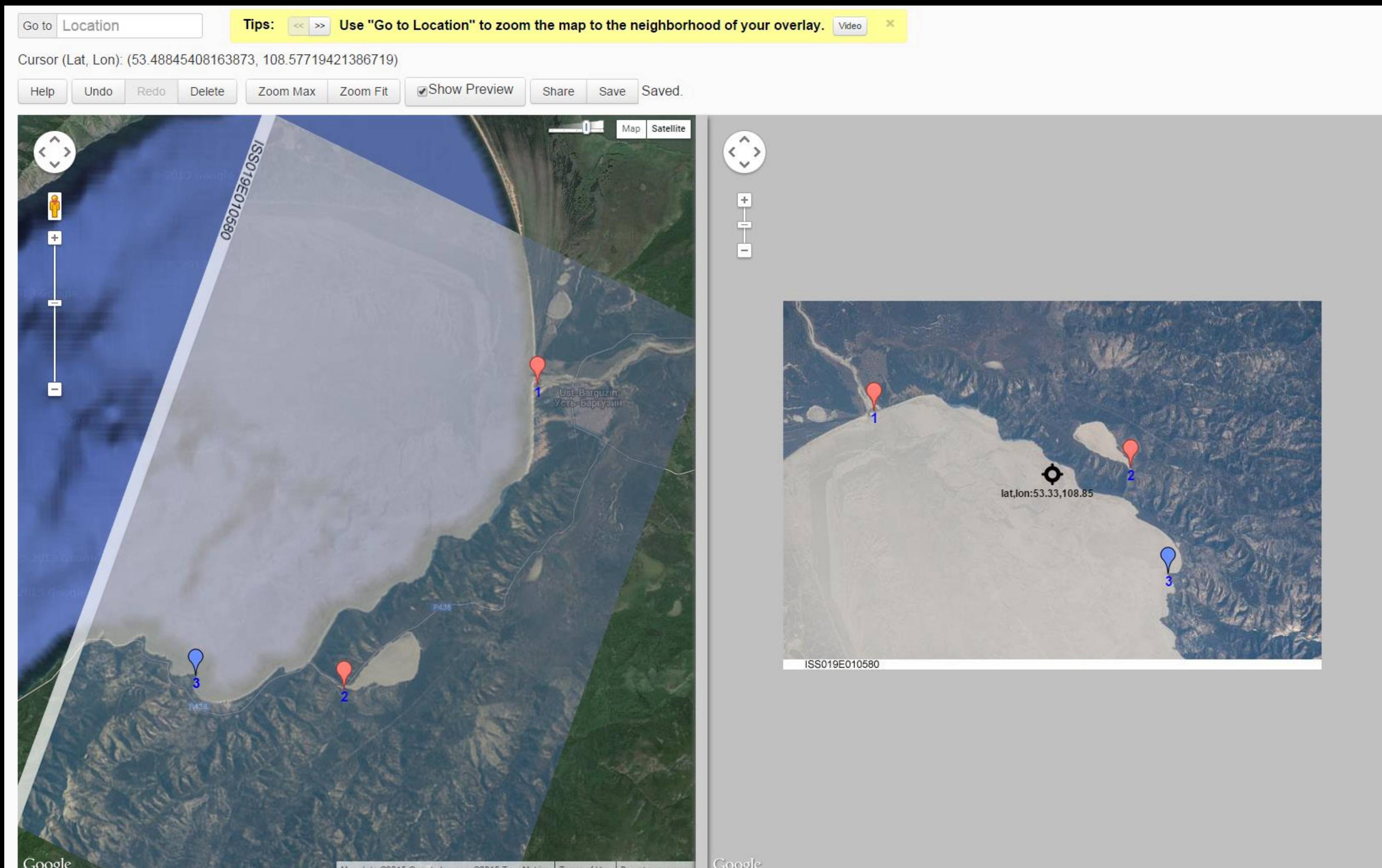
POINTING CALIBRATION TARGET IN ISS INTERIOR

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

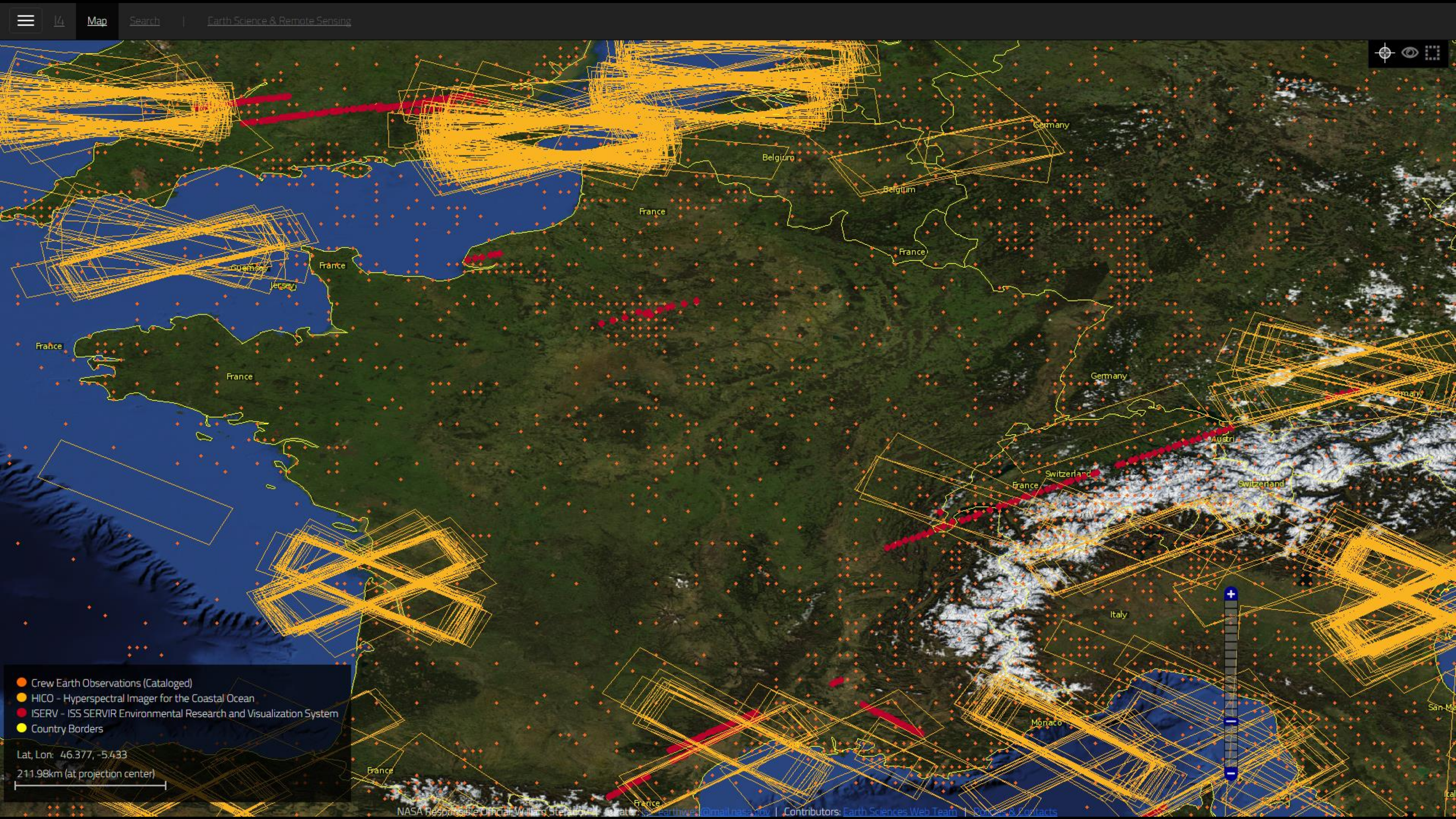
GeoCam Space System – late 2016/early 2017

GeoRef Software (NASA Ames)



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

I4 Search Tool for ISS Earth Obs Data



http://issearthserv.jsc.nasa.gov

BACKUP

ISERV (stowed), Disaster Response Interfaces

Other USOS Sensor Systems & Capabilities relevant to Earth Science

Internal

NHK 4K Camera [2013] – super-sensitive 4K camera system, Kibo (JAXA)
METEOR [2016] – visible spectrometer for observation of meteors in Earth orbit, WORF

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)

NASA Earth Obs – ISERV (stowed)

Sensor: ISS SERVIR Environmental Research and Visualization System (ISERV) Pathfinder

Location: WORF, internal

Sponsor/Funding: NASA SERVIR, ISS National Lab

Prime Mission: Disaster analysis and support of humanitarian response; also agriculture, archeology, deforestation applications

ISS Timeframe: 2012 - 2015

Principal Investigator: Burgess Howell, MSFC

Pointing capability: 23 degrees along & cross-track

Geometric resolution: 2.8 meter nominal

Spectral sensitivity: visible to near-infrared wavelengths (0.35 – 0.80 µm)

Scene Size: 14.4 km x 9.6 km at 350 km altitude

Data take to availability time: ~ 3 hours nominal

Data availability: Public; short term storage at NSSTC/MSFC, long term archival storage TBD

ISERV system, including Canon EOS 7D camera body (not shown); Celestron 925 CPC telescope tube and 800 CPC pointing mount; and Hyperstar 3 lens

ISS034-E-29968

ISS034-E-29960

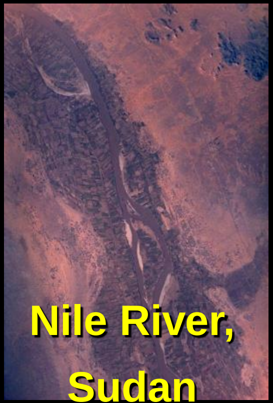
ISS SERVIR Environmental Research and Visualization System (ISERV)
(Prime mission completed 2014, in stowage)


Floods in Calgary, AB, June 22, 2013


Floods/Landslides, N. India, June 28, 2013


San Diego, California


Mulanje, Malawi


Nile River, Sudan


Lake Titicaca


Huntsville, Alabama


Grand Canyon


Andes Mts, Chile

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.

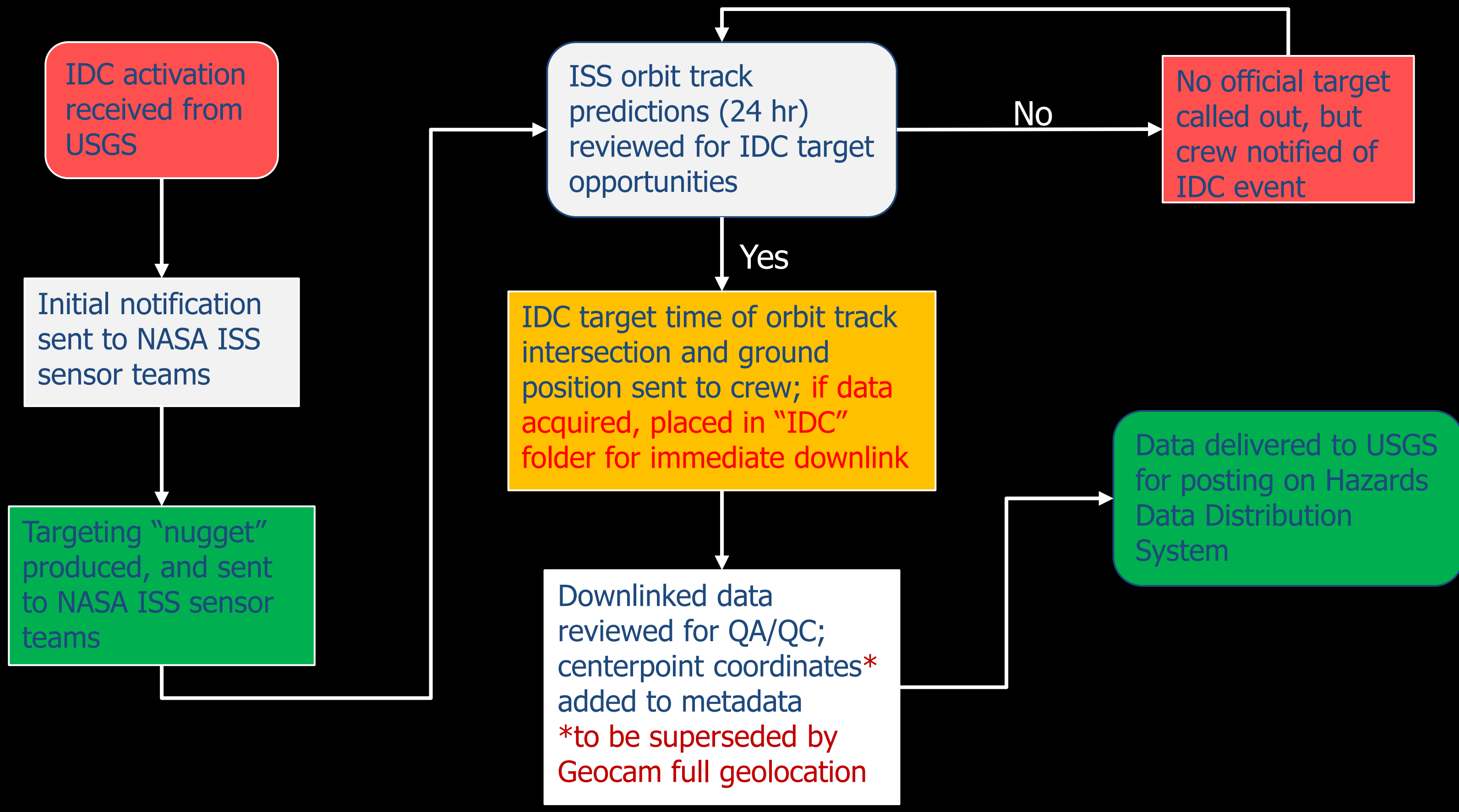
Member Agencies:

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)

Site Plan Information

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.
Window: Any available
Lens: 50-180mm oblique, 400-1200mm near nadir
Viewing angle: Near Vertical, Oblique
Season: 25APR15 through 05MAY15
Maximum clouds: 50%
Frequency: As visible

Nugget

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.

Sized Reference Map

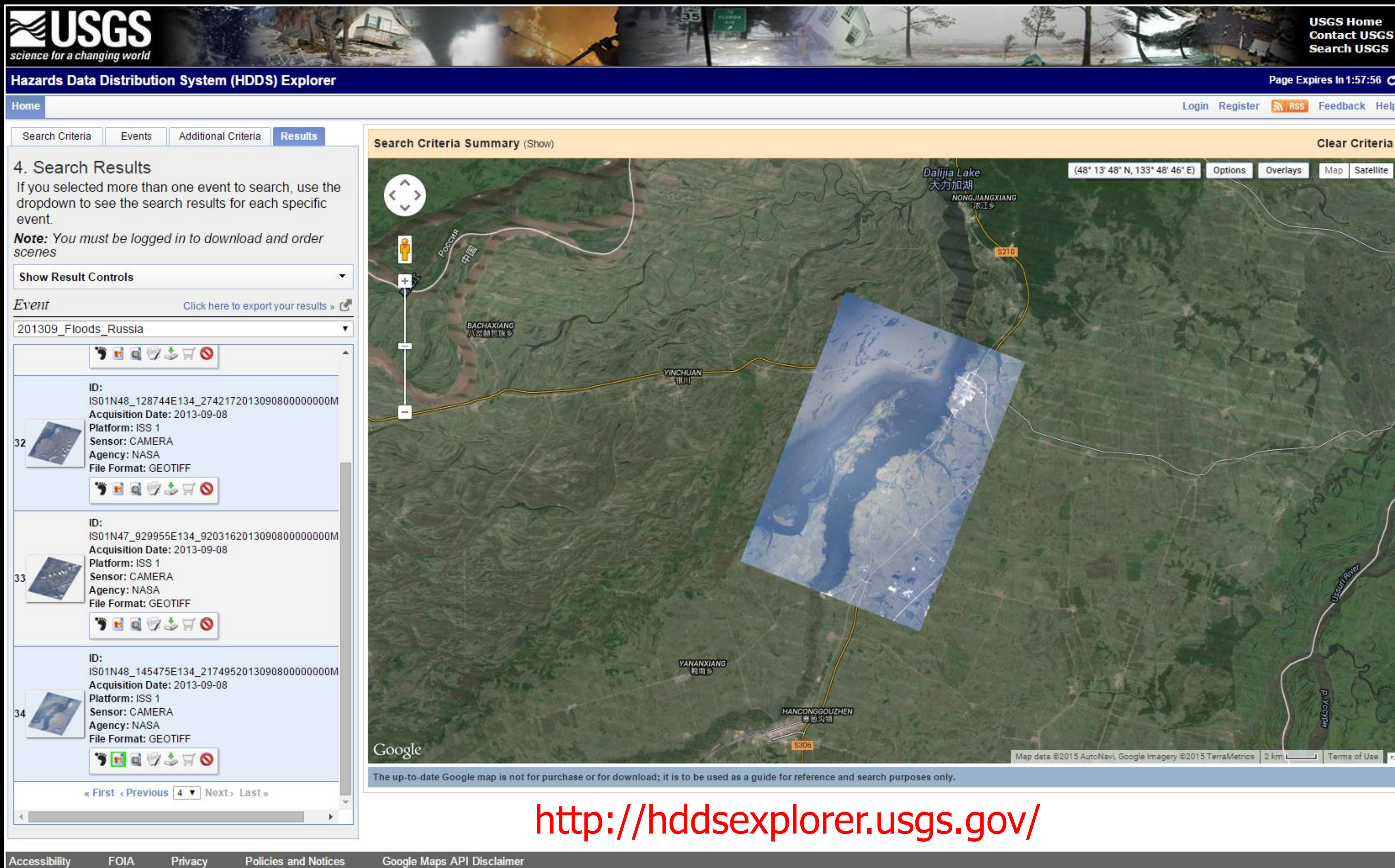
Recommended Site Coordinates:

Type: Box

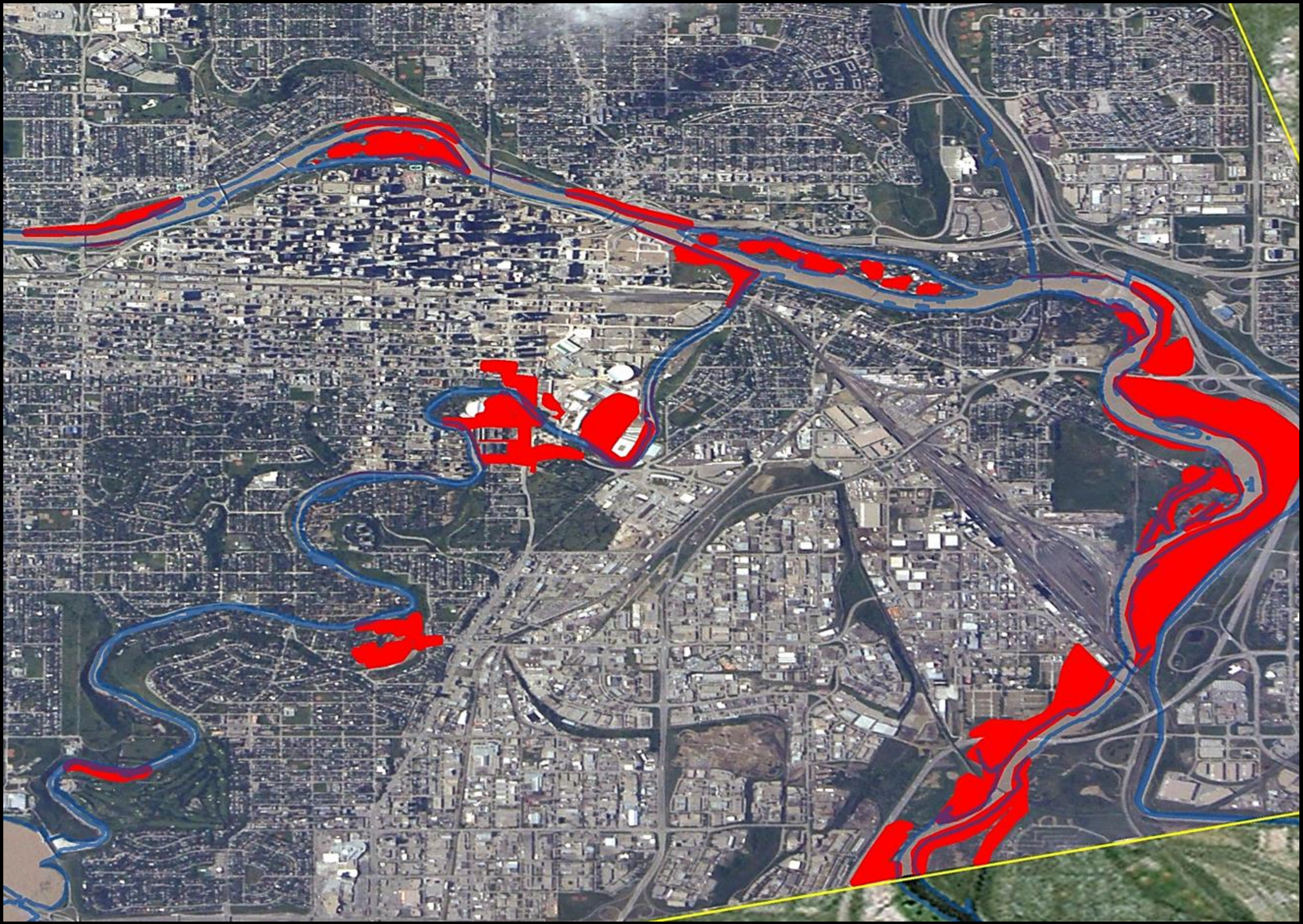
Coordinates:
28.6N 79.6E
27.1N 83.7E
24.3N 83.0E
24.3N 87.8E
28.1N 89.3E
28.2N 86.2E
30.9N 81.1E

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

USGS Hazards Data Distribution System



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