Opportunities in Earth Observation: Small Sats and the Coming Boom of Commercial Remote Sensing

A NASA Earth Science Perspective

GEO-Energy Summit

Michael Goodman

13 November 2014

GEO-Energy Summit 2014

Nov 2014

Currently have 18 satellites in orbit

6 in Primary ops

12 in Extended ops

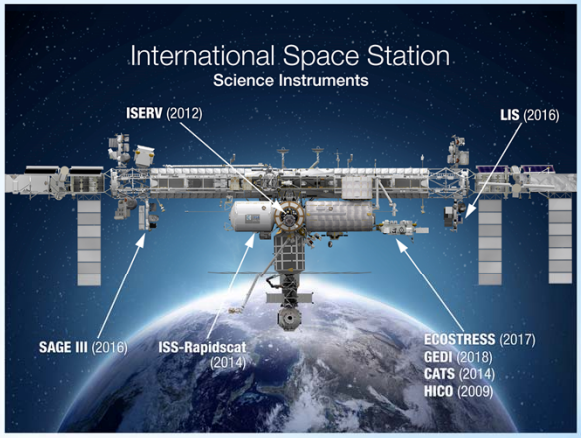
7 in Implementation

4 in Formulation

Extensive Earth Data Collection

Earth Observation Data & Information System collection includes over 6800 data types

- **Land**
  - Cover & Usage
  - Surface temperature
  - Soil moisture
  - Surface topography
- **Atmosphere**
  - Winds & Precipitation
  - Aerosols & Clouds
  - Temperature & Humidity
  - Solar radiation
- **Ocean Dynamics**
  - Surface temperature
  - Surface wind fields & heat flux
  - Surface topography
  - Ocean color
- **Cryosphere**
  - Sea/Land Ice & Snow Cover

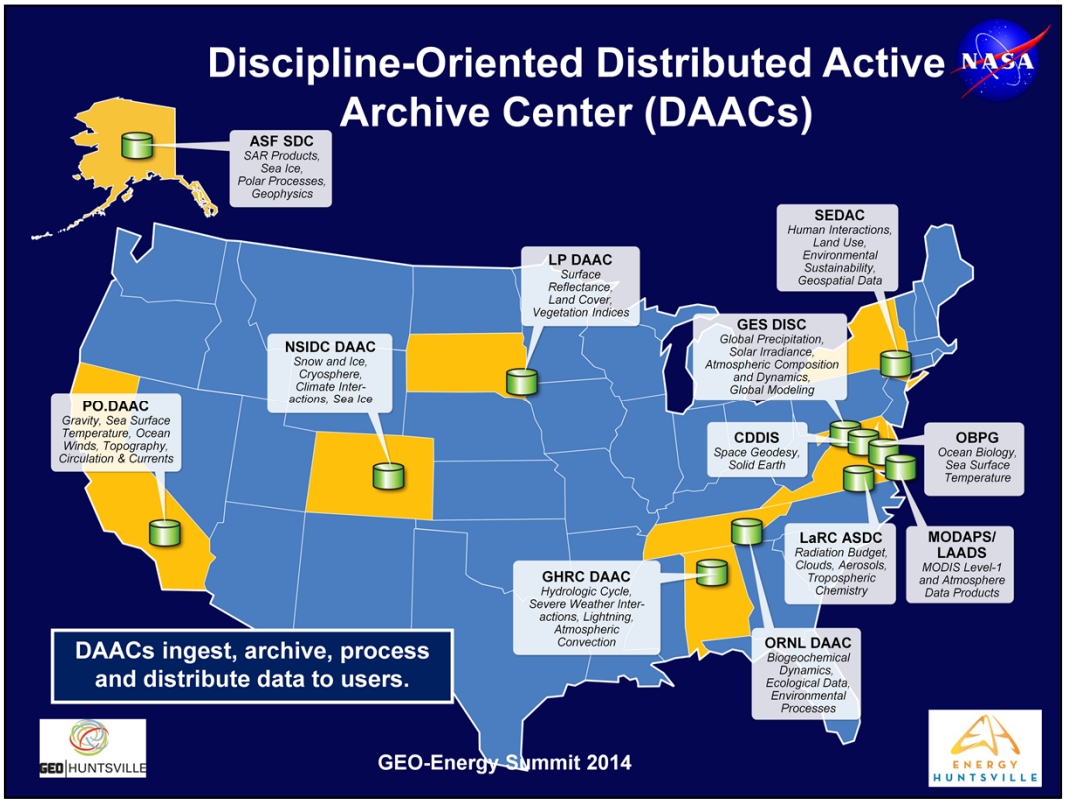


- **Human Dimensions**
  - Population & Land Use
  - Human & Environmental Health
  - Ecosystems

GEO HUNTSVILLE

GEO-Energy Summit 2014

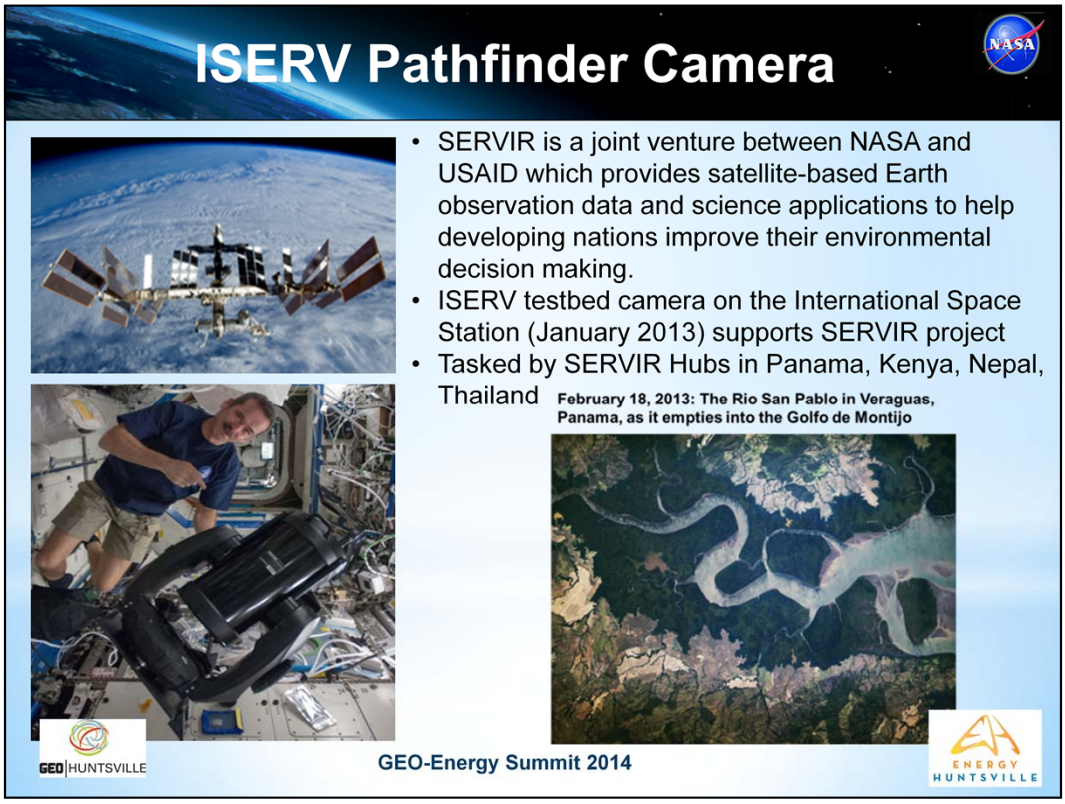
ENERGY HUNTSVILLE


Discipline-Oriented Distributed Active Archive Center (DAACs)
NASA
ASF SDC
SAR Products, Sea Ice, Polar Processes, Geophysics
SEDAC
Human Interactions, Land Use, Environmental Sustainability, Geospatial Data
LP DAAC
Surface Reflectance, Land Cover, Vegetation Indices
GES DISC
Global Precipitation, Solar Irradiance, Atmospheric Composition and Dynamics, Global Modeling
NSIDC DAAC
Snow and Ice, Cryosphere, Climate Inter-actions, Sea Ice
PO.DAAC
Gravity, Sea Surface Temperature, Ocean Winds, Topography, Circulation & Currents
CDDIS
Space Geodesy, Solid Earth
OBPG
Ocean Biology, Sea Surface Temperature
LaRC ASDC
Radiation Budget, Clouds, Aerosols, Tropospheric Chemistry
MODAPS/ LAADS
MODIS Level-1 and Atmosphere Data Products
GHRC DAAC
Hydrologic Cycle, Severe Weather Inter-actions, Lightning, Atmospheric Convection
ORNL DAAC
Biogeochemical Dynamics, Ecological Data, Environmental Processes
DAACs ingest, archive, process and distribute data to users.
GEO HUNTSVILLE
GEO-Energy Summit 2014
ENERGY HUNTSVILLE

NASA Earth Science Data Policy

- NASA commits to the **full and open sharing of Earth science data** obtained from NASA Earth observing satellites, sub-orbital platforms and field campaigns with all users **as soon as such data become available**.
- There will be **no period of exclusive access** to NASA Earth science data. Following a post-launch checkout period, all data will be made available to the user community. Any variation in access will result solely from user capability, equipment, and connectivity.
- NASA will make available all **NASA-generated standard products** along with the source code for algorithm software, coefficients, and ancillary data used to generate these products.
- NASA will enforce a principle of non-discriminatory data access so that **all users will be treated equally**. For data products supplied from an international partner or another agency, NASA will restrict access only to the extent required by the appropriate Memorandum of Understanding (MOU).

http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/



As a preliminary step, we deployed a *Pathfinder* imaging system for developmental testing in WORF
What we expected:

- Low-cost Pathfinder testbed instrument to buy down programmatic and technical risk for future operational Earth observing systems aboard the ISS
- Operational experience to inform the design of more capable ISS-based imaging systems
    - development of general tasking, utilization, ground command, data acquisition, and processing routines
    - development of image acquisition, processing, and analysis methods
    - implementation of full command, acquisition, and processing systems for humanitarian aid & disaster monitoring and assessment operational requirements
- **Acquisition of images with utility for humanitarian assistance and Earth science applications**

The International Space Station SERVIR Environmental Research and Visualization System (ISERV) is a testbed Earth imaging system, intended primarily as a platform for the development of processes and procedures necessary for the operation of future, more capable imagers aboard the ISS. ISERV images have been used by environmental decision makers around the world, and have proven to be particularly valuable in the support of natural disaster response, assessment, and monitoring. ISERV has provided data to domestic and international agencies in response to over two dozen disasters worldwide since its activation in late January, 2013.

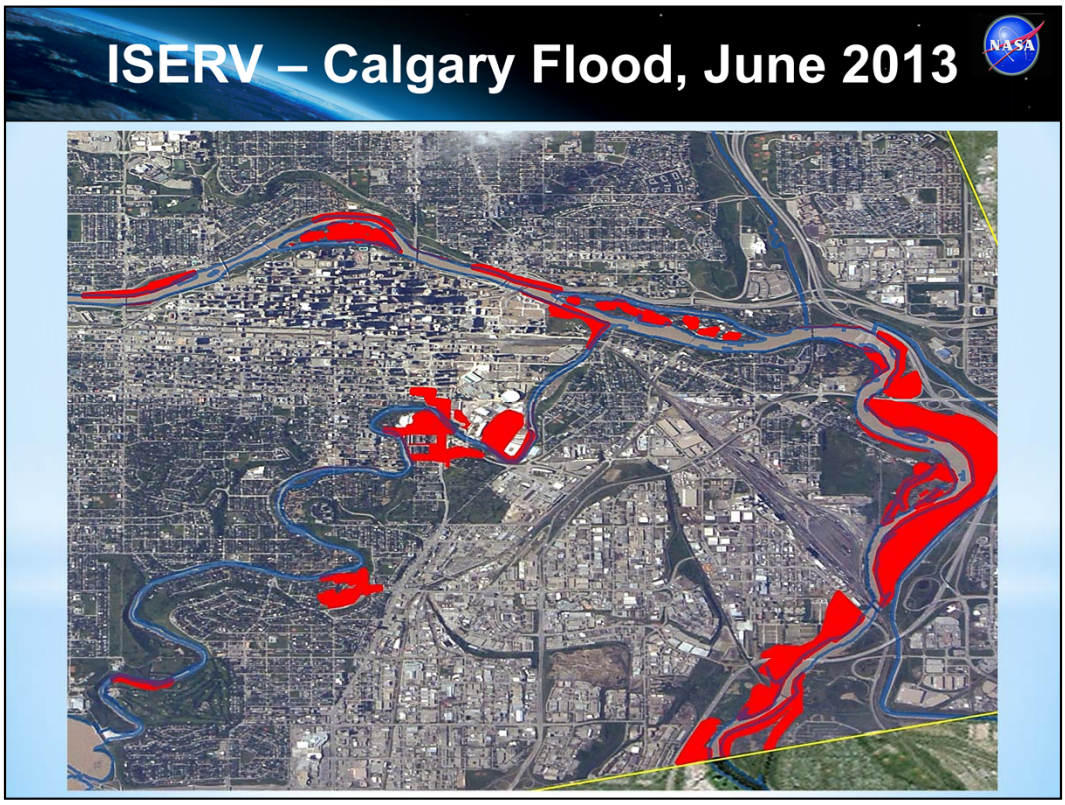
ISERV acquires images of the Earth, typically at a rate of 3 frames per second, for up to 5 minutes per target, producing visible spectrum data with 5-meter resolution across a footprint of 18 km x 12 km at 420 km altitude. ISERV is expected to operate through mid-January of 2015.

•ISERV *Pathfinder* is designed to be a low cost, high return on investment system

•Primary components are commercial, off the shelf items

- •9.25” aperture Schmidt-Cassegrain telescope on alt-az mount
- •Digital single lens reflex camera
- •Focal reducer

•Provides visible spectrum data at moderate resolution



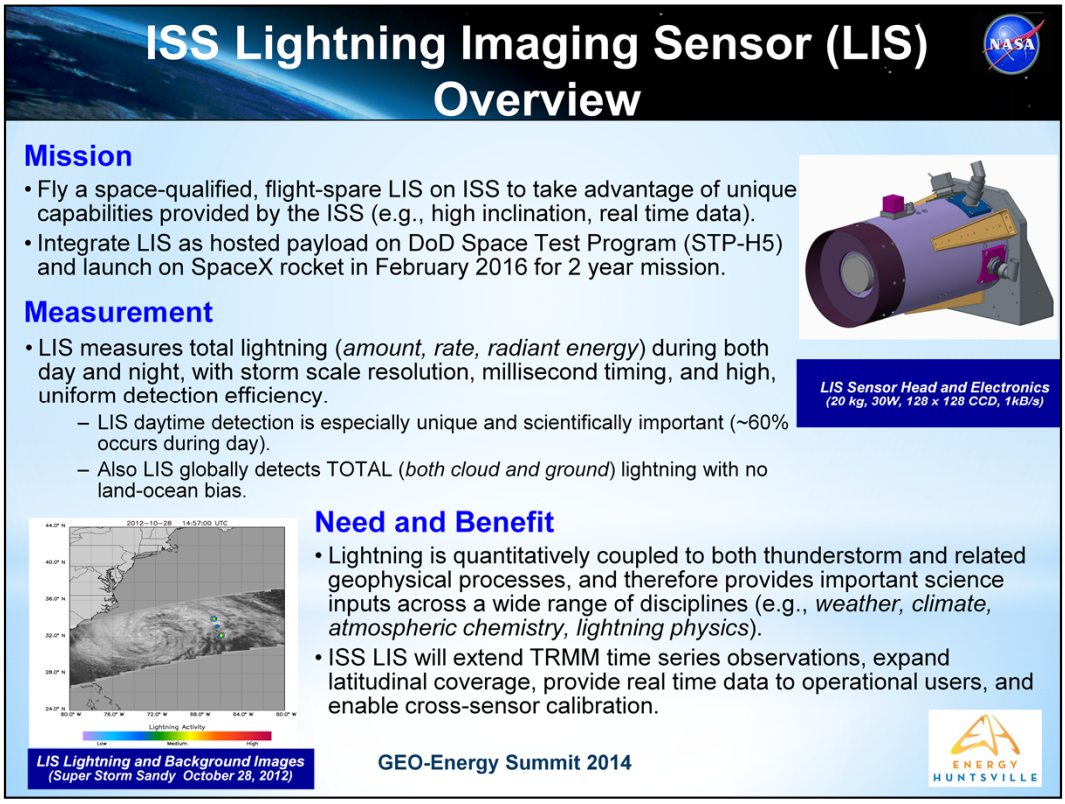
This ISERV image shows the flooding along the Bow River (arcs from northwest to south) and Elbow River (flows southwest to northeast) at their confluence in Calgary, Alberta, Canada, on June 22, 2013. Normal river levels are shown in blue; flooded regions in red. Flooded areas include downtown Calgary (upper left of center), the Calgary Stampede (immediately beneath downtown), the Calgary Zoo and Inglewood Golf & Curling club (far right), and municipal water treatment facility (lower right).

This image is part of four separate series (approximately 140 images in total) acquired June 22-24, 2013, documenting the flood peak and recovery around Calgary. The complete image set, provided to the Royal Canadian Mounted Police and other Canadian agencies for use in allocating response assets in the aftermath of the flood, represents an excellent example of how the ISS orbit can provide rapid repeat overpasses for Earth observations, as well as how ISERV capitalizes upon that capability to support disaster response, assessment, and monitoring.

Flood: Khor, Russia

After: ISERV 8 Sep 2013
Before: GeoEye 25 Aug 2006

- Ussuri River near Khor, Russia
- Single scene contains over 100 km2 flooded



Again, we have been selected to fly a Lightning Imaging Sensor on the International Space Station in order to take advantage of unique capabilities provided by the space station.

To get to the space station, the LIS will be flown as a hosted payload on the DoD Space Test Program STP-H5 mission, which will be launched on a Space X launch vehicle in February 2016 for a 2 year mission.

NASA and her partners developed this technology and instrument, and with it have demonstrated the effectiveness and value of using space-based lightning observations as a remote sensing tool to address a variety of science and applications problems.

So what LIS actually measures is the amount, rate and radiant energy of global lightning, and it does this during both day and night, with storm scale resolution, millisecond timing, and high, uniform detection efficiency.

Especially unique and scientifically important is the LIS daytime lighting detection, and that's when most lightning occurs.

(In addition, LIS globally detects what we call TOTAL lightning, and it does this without any land-ocean bias).

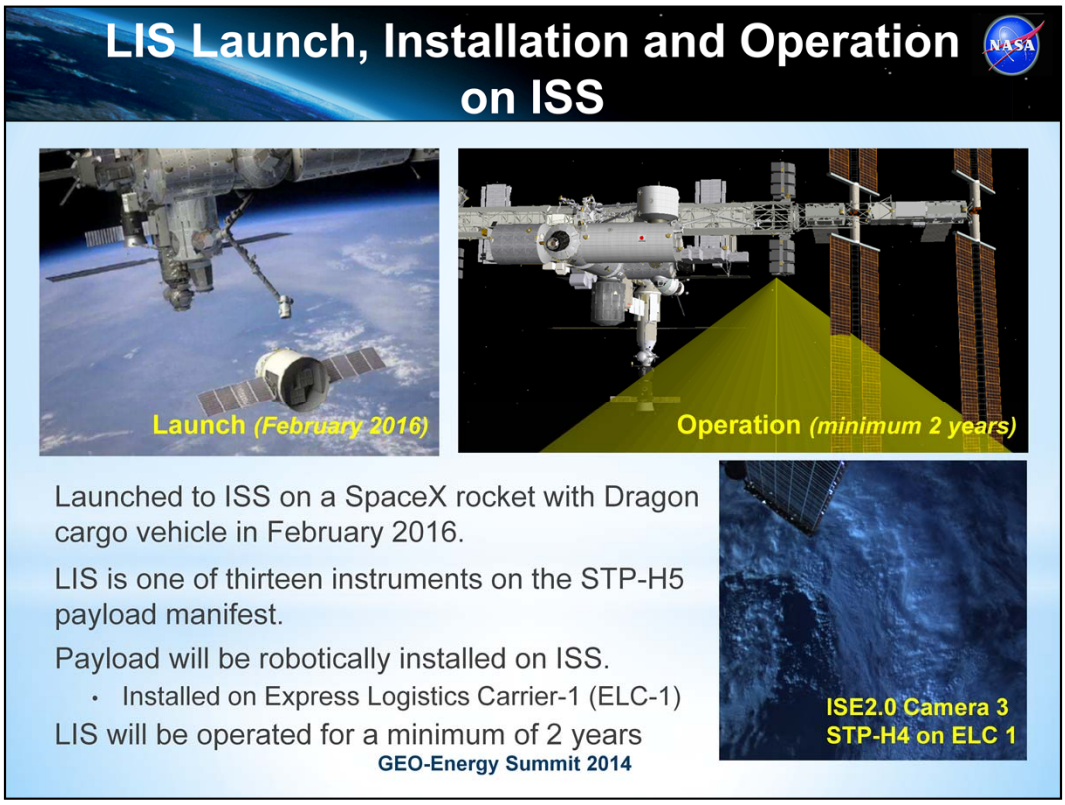
Lightning is a direct and most impressive response to intense atmospheric convection:

It has been found that lightning can be quantitatively related to both thunderstorm and related geophysical processes, and

THEREFORE, provides important science inputs across a wide range of disciplines (that include weather, climate, atmospheric chemistry and lighting physics).

The ISS LIS or iLIS as Hugh Christian prefers to call this mission, will extend TRMM time series observations, expand latitudinal coverage, provide real time lightning data to

operational users and enable cross-sensor calibrations.



In August 2015, the STP-H5 payload will be shipped to NASA Kennedy Space Center for launch vehicle integration and tests.

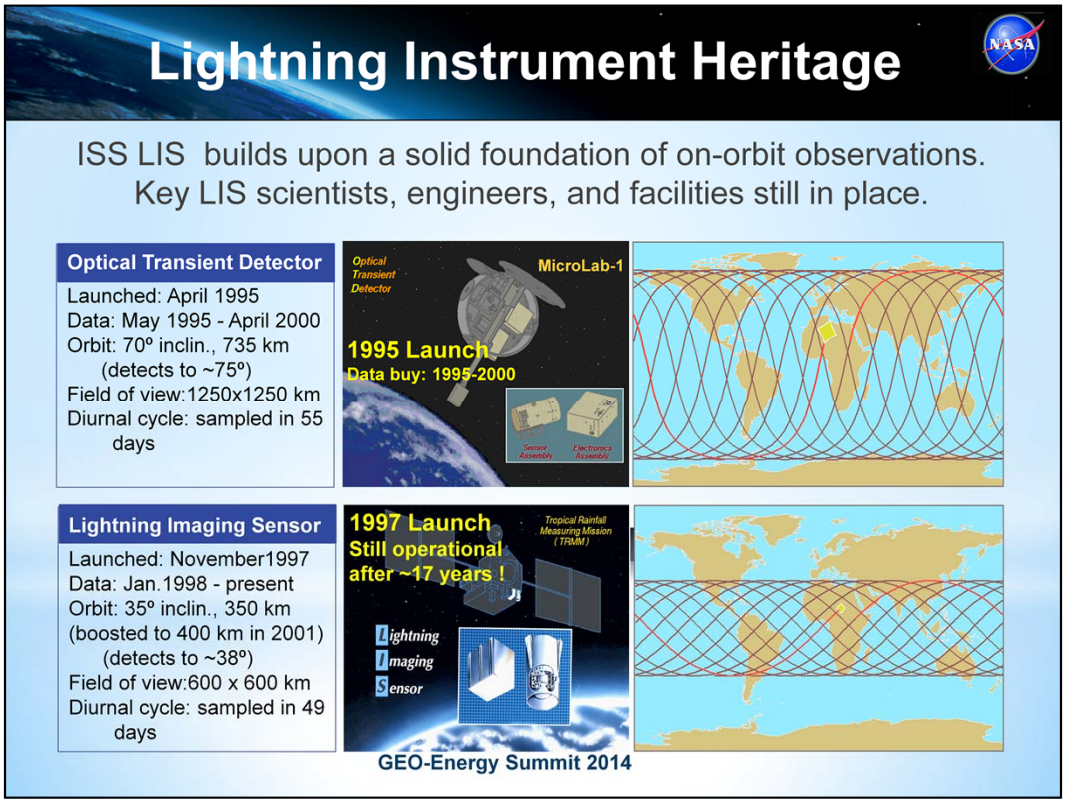
Then in February 2016 – about a year and a half from now – the LIS will be launched to the ISS on a Space X rocket.

Once on orbit, the payload will then be robotically transferred from the Dragon cargo vehicle and installed on an external truss of the space station in the position shown in the figure in the upper right.

The figure in the lower right gives a sense of the field-of-view that LIS will have once on-orbit.

The LIS will be operated on the space station for a minimum of 2 years, but we plan to seek a mission extension from NASA for a few additional years.

ISS= 420km altitude, 51.6 deg inclination



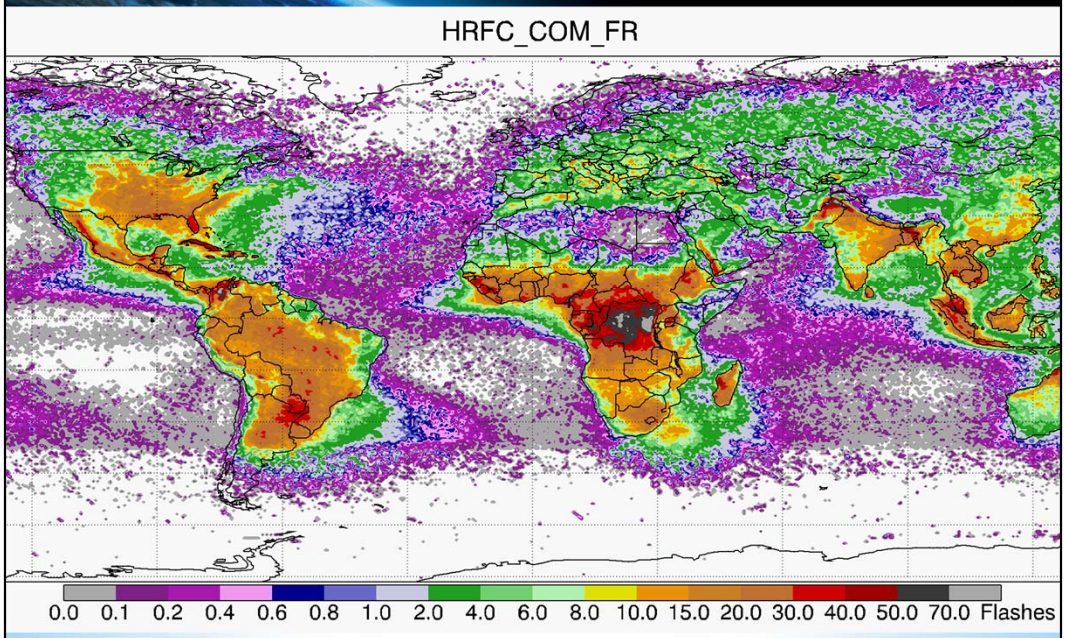
The ISS LIS mission is built upon a solid foundation of on-orbit observations, now extending to 19 years.

It began with the launch of the Optical Transient Detector in 1995. OTD was a space-qualified Engineering model of LIS. It was operated for 5 years and served as a proof-of-concept for this approach to making lightning observations from space.

In 1997, LIS was launch on the TRMM satellite for a 3 year mission. Unbelievably, TRMM LIS is still operational after 16 years on orbit, and it could still be in operation when ISS LIS is launched in February 2016. (The altitude of TRMM is very similar to that of the ISS).

An important consequence of the longevity of the TRMM mission, is that the key scientists, engineers, and facilities are all still in place to support the ISS mission making it much easier and less expensive to implement.

Lightning Climatology 1995-2013

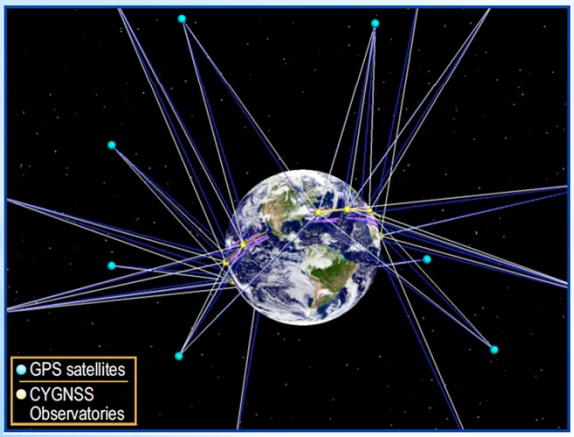


GEO-Energy Summit 2014

CYGNSS:
Cyclone Global Navigation Satellite System

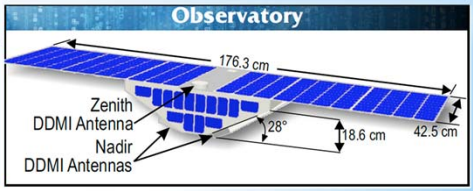
Key Science Products:

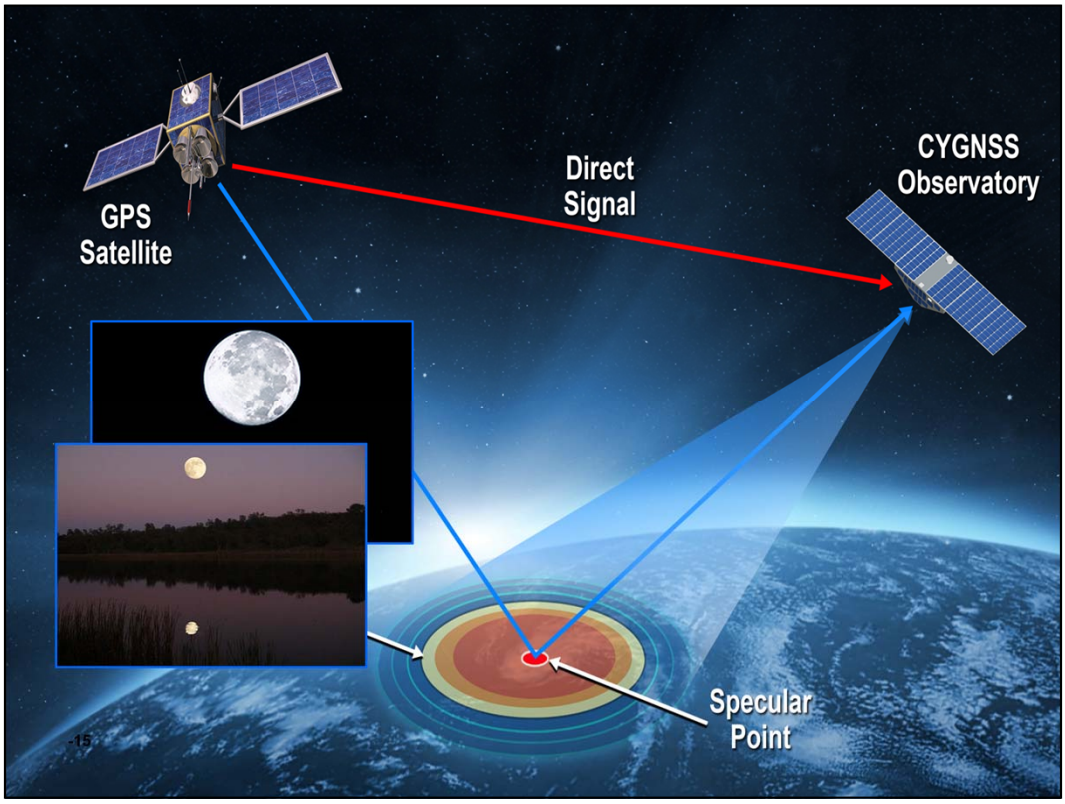
Measure ocean surface wind speed in extreme precipitating conditions, including those experienced in the cyclone eyewall such that hurricane genesis and intensification can be resolved



Mission Description:

PI: Chris Ruf, U. of Michigan
S/C: Southwest Research Institute
Instrument: Surrey Satellite Tech.
Orbit: 500 km and 35° inclination
Mission Life: 2 years
Launch Date: Oct 2016





Bi-static scattering geometry with GPS direct signal proving reference and quasi-specular forward scattered signal containing ocean surface roughness information

Animation illustrates – propagation and scattering geometries – GNSS bi-static scatterometry

- •quasi-specular forward scattered signal from the ocean surface -- received by nadir antenna array
  - •Ideal reflected signal (perfect ocean surface) -- mirror image of direct
  - •scattered signal contains detailed information about surface roughness statistics
  - •Glistening zone broadens from perfect surface to broad area given increase in surface wind speed.
    - •Use example of Sun reflection while flying on airplane overwater to conference

- •direct GPS signal -- coherent reference for the coded GPS transmit signal – received by zenith ant

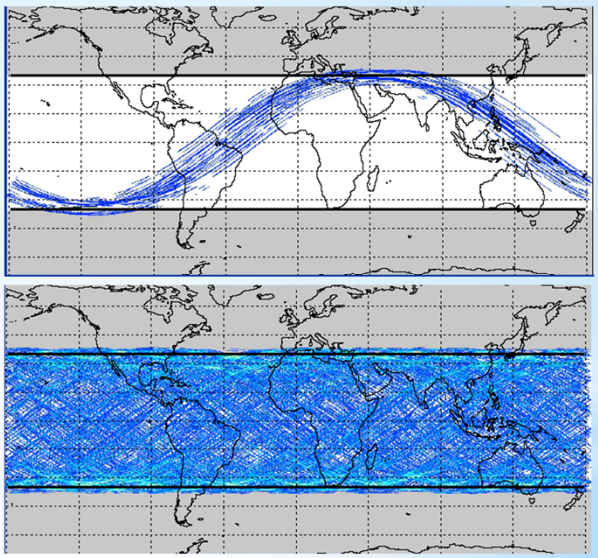
Inset: Image produced from data by the UK-DMC-1 demonstration spaceborne mission shows scattering cross-section

- •Two coordinates of the image:
  - •Variable lag correlation (signal delay)
  - •Doppler shift
- •The DDM enable the spatial distribution of the GPS signal surface scattering cross section to be resolved
- •Measurement of the ocean surface roughness and near-surface wind speed is possible from two properties of the DDM
  - •The scattering cross-section can be related to surface roughness which corresponds to near surface wind speed
  - •Wind speed can also be estimated from the shape of the scattering arc (the red and yellow regions)
    - •The arc represents the departure of the actual bi-static scattering from the purely specular case that would correspond to a perfectly flat ocean surface

CYGNSS Orbit and Daily Coverage

- Temporal sampling is not deterministic due to asynchronous CYGNSS and GPS orbits
- Model revisit time as a random variable with empirical probability density function derived from Monte Carlo simulations
- (Top) 90 min (one orbit) coverage showing all specular reflection contacts by each of 8 spacecraft
- (Bottom) 24 hr coverage used to derive revisit pdf

- **Median revisit time = 2.8 hr**
- **Mean revisit time = 5.9 hr**



-16

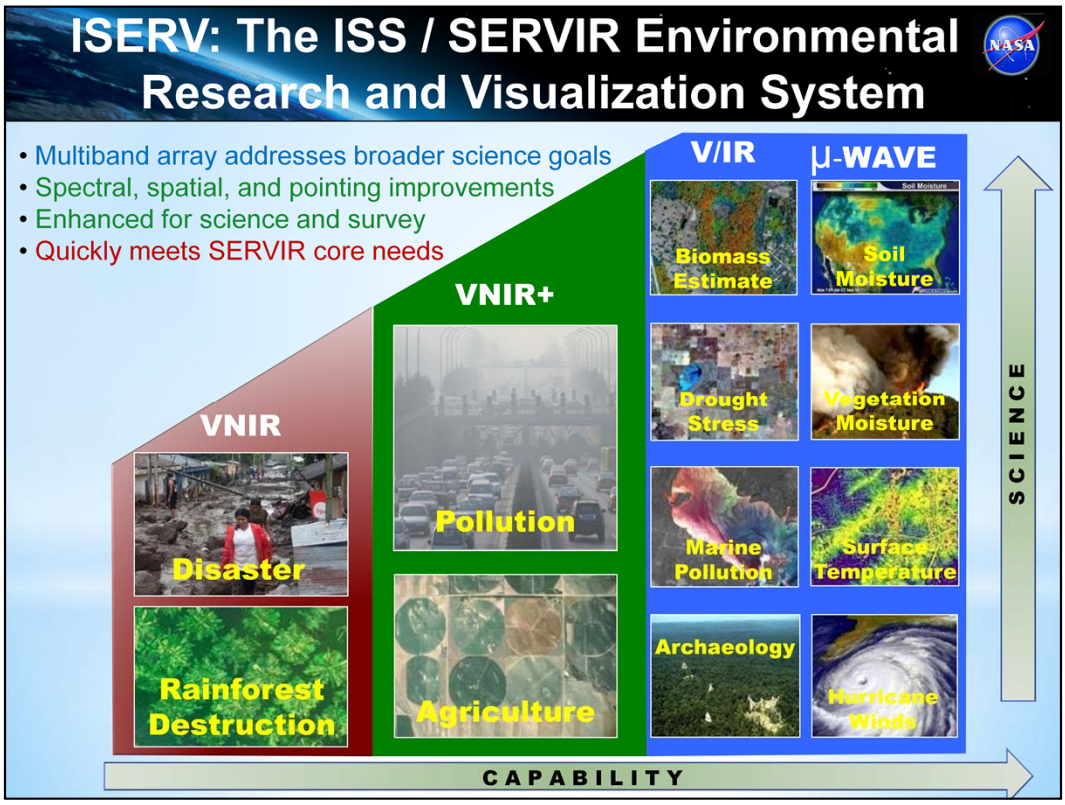
pdf = probability density function = probability that the random variable falls within some very small interval

Thank You for Your Interest

GEO-Energy Summit 2014

Backup

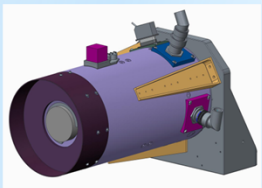
GEO-Energy Summit 2014

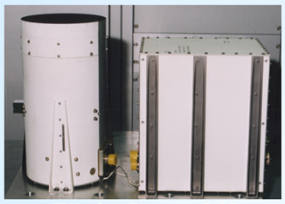


- ISERV was envisioned as a suite of Earth observing instruments aboard the international Space Station, with each phase strengthening its capabilities and extending its science utility
- ISERV Pathfinder is a preparatory step for this suite

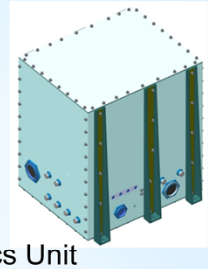
- ISERV *Pathfinder* is designed to be a low cost, high return on investment system
- Primary components are commercial, off the shelf items
    - 9.25" aperture Schmidt-Cassegrain telescope on alt-az mount
    - Digital single lens reflex camera
    - Focal reducer
- Provides visible spectrum data at moderate resolution

LIS Hardware





Flight Spare LIS



LIS Sensor Unit
Optical Assembly
128x128 CCD Focal Plane

Electronics Unit
Real Time Event Processor and
Background removal
Control & Data Handling (C&DH)
Power conversion and control

Interface Unit (***new***)
Power conversion
1 PPS Time Signal Generation
C&DH Formatting
ISS Interface

LIS in Calibration

LIS Performance Parameters

Field-of-View (FOV)	80° × 80°	Measurement Accuracy	
Pixel IFOV (nadir)	4 km	location	1 pixel
Interference Filter		intensity	10 %
wavelength	777.4 nm	time	tag at frame rate
bandwidth	1 nm	Dimensions	
Detection Threshold	4.7 $\mu J\ m^{-2}\ sr^{-1}$	sensor assembly	20 × 37 cm
Signal to Noise Ratio	6	electronics assembly	31 × 22 × 27 cm
CCD Array Size	128 × 128 pixels	Weight	20 kg
Dynamic Range	> 100	Power	30 Watts
Detection Efficiency	~ 70 - 90 %	Telemetry	
False Event Rate	< 5 %	data rate, format	8 kb/s, PCM

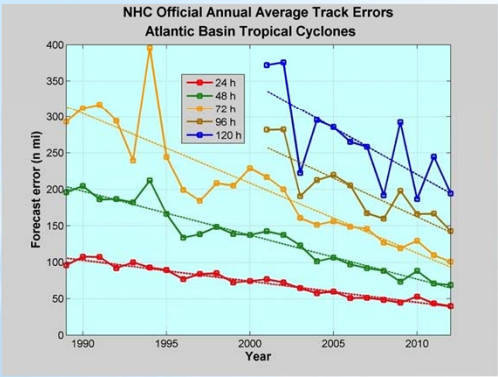
This slide shows the LIS hardware that will be flown.

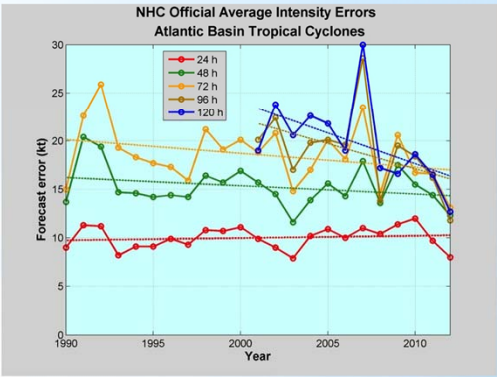
It consists of the LIS sensor unit and electronics assembly that were built as flight spares for the TRMM mission.

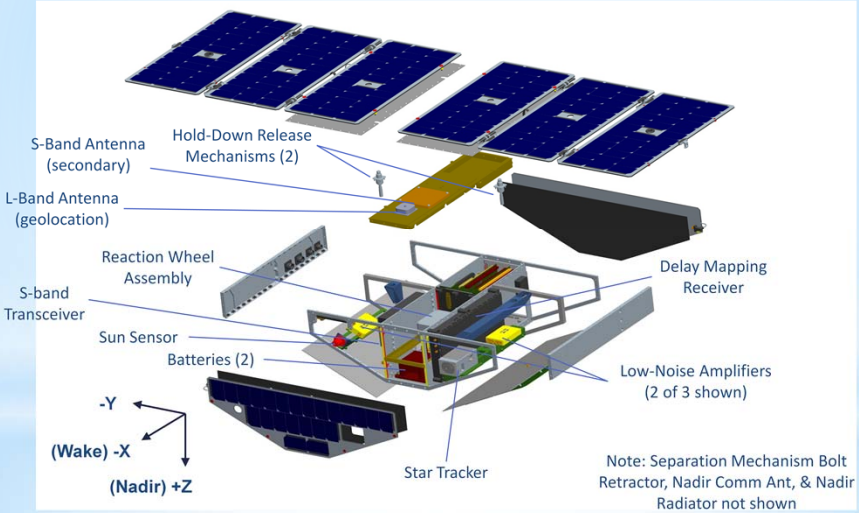
It also includes a new interface box that will allow the legacy LIS hardware to communicate with the space station without requiring any modifications to be made the legacy hardware – basically this makes the ISS look and act like the TRMM spacecraft.

As the picture in the lower left shows, we have just started the re-calibration of LIS instrument. We are happy to report that the legacy LIS hardware is fully operational and it is performing beautifully after 17 years in controlled storage.

Tropical cyclone track forecasts have improved in accuracy by ~50% since 1990, largely as a result of improved mesoscale and synoptic modeling and data assimilation. In that same period, there has been essentially no improvement in the accuracy of intensity forecasts.





National Hurricane Center, http://www.nhc.noaa.gov/verification/verify5.shtml

μSat Configuration (back)