Benchmarking of the HyspIRI VSWIR Compression, Level 1 and Level 2 Algorithms

Sarah Lundeen, Robert O. Green, Bo-Cai Gao, Didier

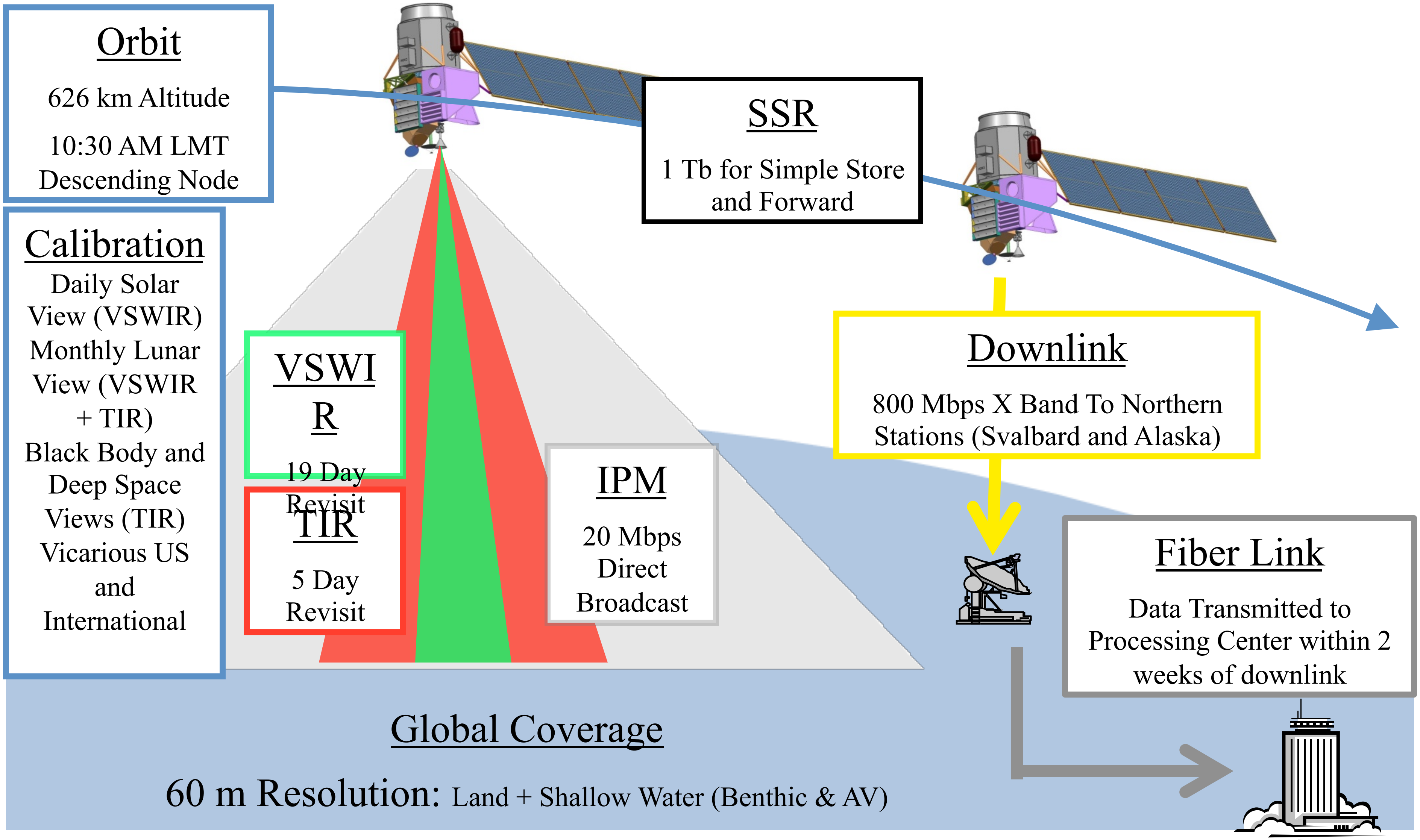
Overview

- Challenge and Objective
- HyspIRI VSWIR data rates and volumes
- On-board VSWIR compression
- Ground processing Level 1 data
- Ground processing Level 2 data
- Summary and Conclusions

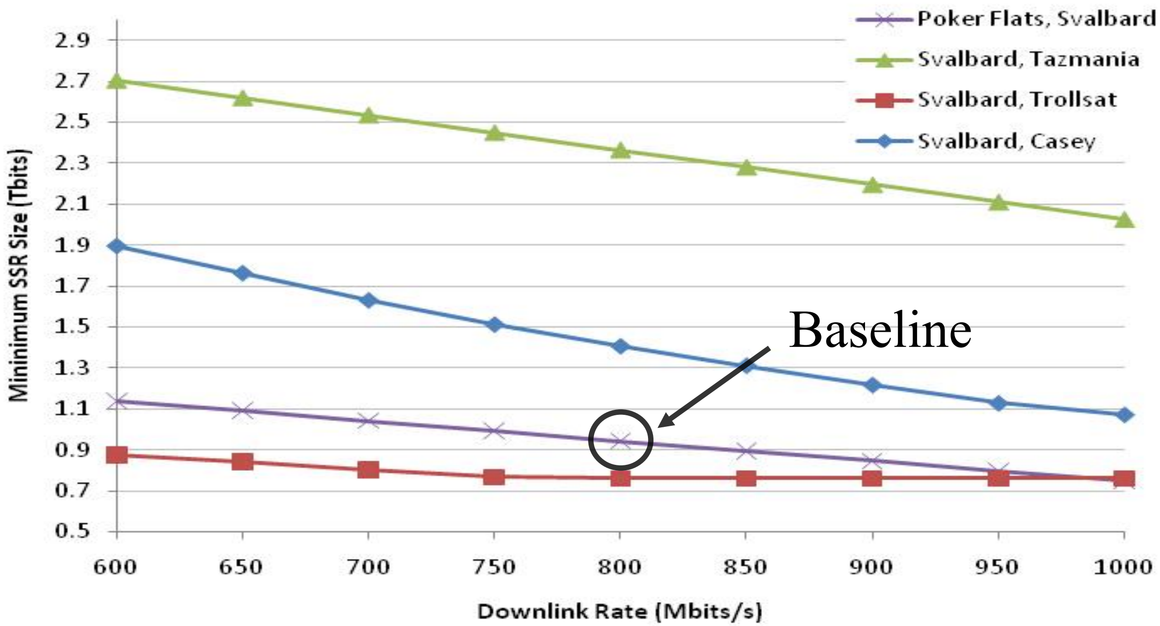
Challenge and Objective

- HyspIRI is a high data rate and volume mission at ~ 1 terabit per orbit and 14 orbits per day
- This data rate lead to challenges of handling the data on the satellite, downlinking the data, and processing the data on the ground
- HyspIRI has mission baseline solutions at all elements of data handling
- The objective of the testing and benchmarking is to demonstration the viability of the solutions using HyspIRI like data
- This work validates the cost estimates and reduces the risk of the HyspIRI

HyspIRI Mission Architecture



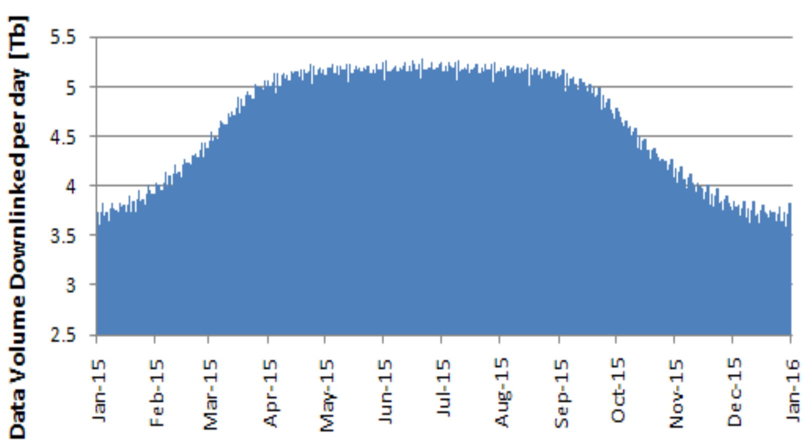
HyspIRI Downlink Data Volume



	Rate	On-board Compression
VSWIR_land	804.1 Mb/s	3:1
VSWIR_shallow	865.9 Mb/s	3:1
VSWIR_ocean	3.9 Mb/s	3:1
TIR_land	130.2 Mb/s	2:1
TIR_shallow	130.2 Mb/s	2:1
TIR_ocean	0.6 Mb/s	2:1

	Avg (Tb)	Min (Tb)	Max (Tb)
Per Day	4.64	3.59	5.29
Per Orbit	0.31	0.00	0.81

Total downlinked data volume for the 3 year mission: 5024



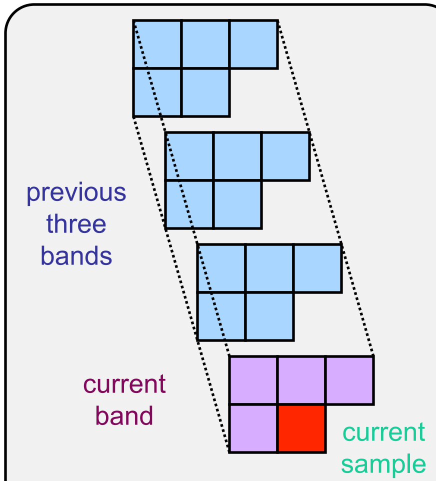
- Baseline selected to minimize system level cost and risk
- On-board storage capacity
  - 1 Tb
  - 0.31 Tb/orbit
- WorldView-1 and -2 have 2.2 Tb SSR
  - WorldView1: 0.33 Tb/orbit
    - Different downlink strategy requires larger SSR than HyspIRI
  - WorldView2: 0.52 Tb/orbit
- 30% margin added to calculated required SSR size

Fast Lossless Compression Algorithm

- **Objective:** State-of-the-art lossless compression, with low complexity (i.e., fast)
- **Approach**: *Predictive compression* that adapts to the data via the sign algorithm (a variation of the *least mean square (LMS) algorithm*) (see boxes below)
- **Compared** to *Transformed-based compression techniques* (such as DCT, Wavelet transform), this approach:
  - requires fewer arithmetic operations and less memory, simplifies data handling, and is more straightforward to implement (in software, DSP, or hardware)
  - yields significantly faster lossless compression
  - But provides only lossless (and potentially near-lossless) compression

Predictive Compression

- Encodes samples one-at-a-time, typically in raster scan order
- Estimates sample value probability distribution from previously encoded samples. These estimates are used to efficiently encode the sample value.
- The difference between an estimated sample value in the actual sample value is encoded in the compressed bitstream.

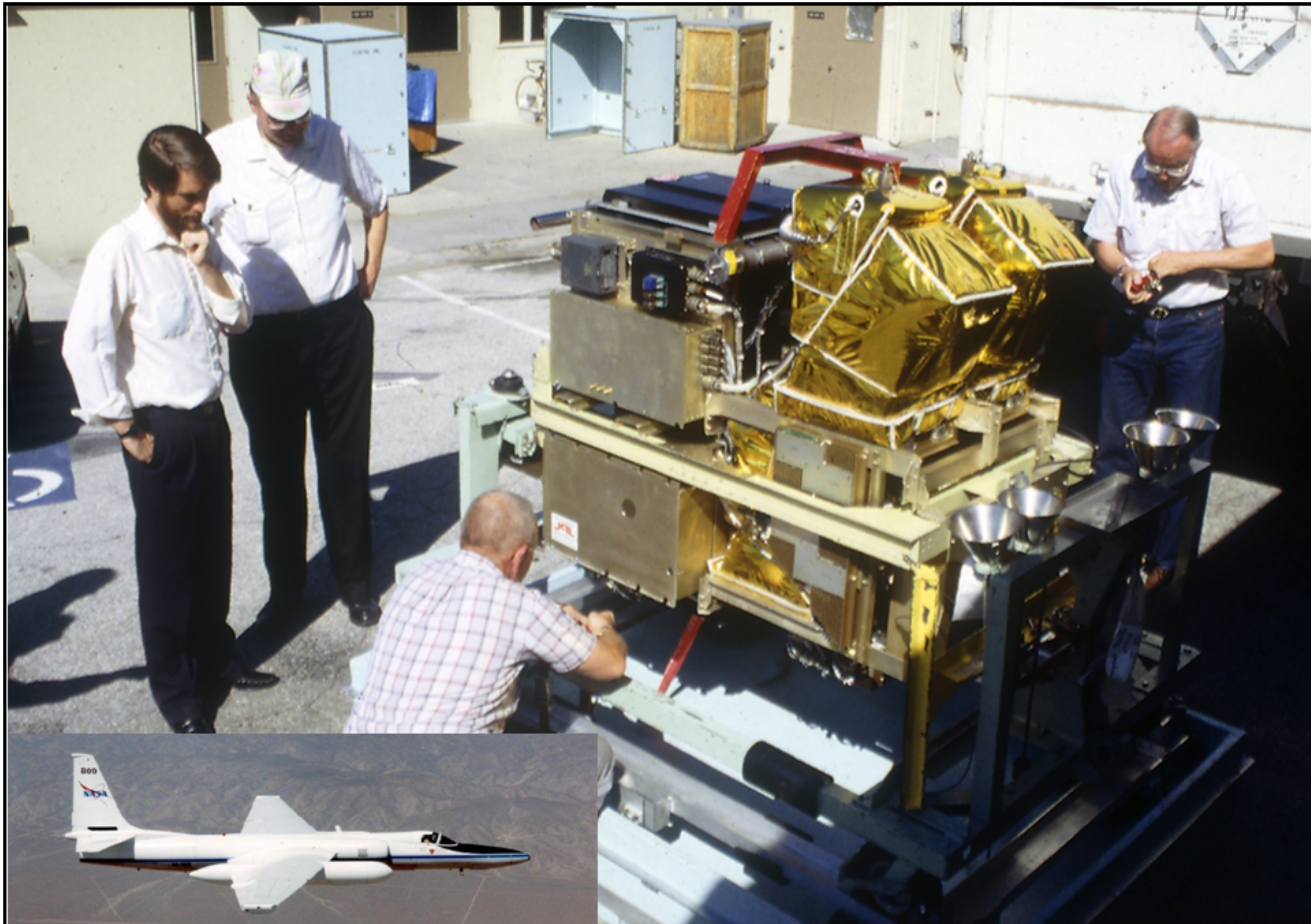


3D neighborhood used for prediction.

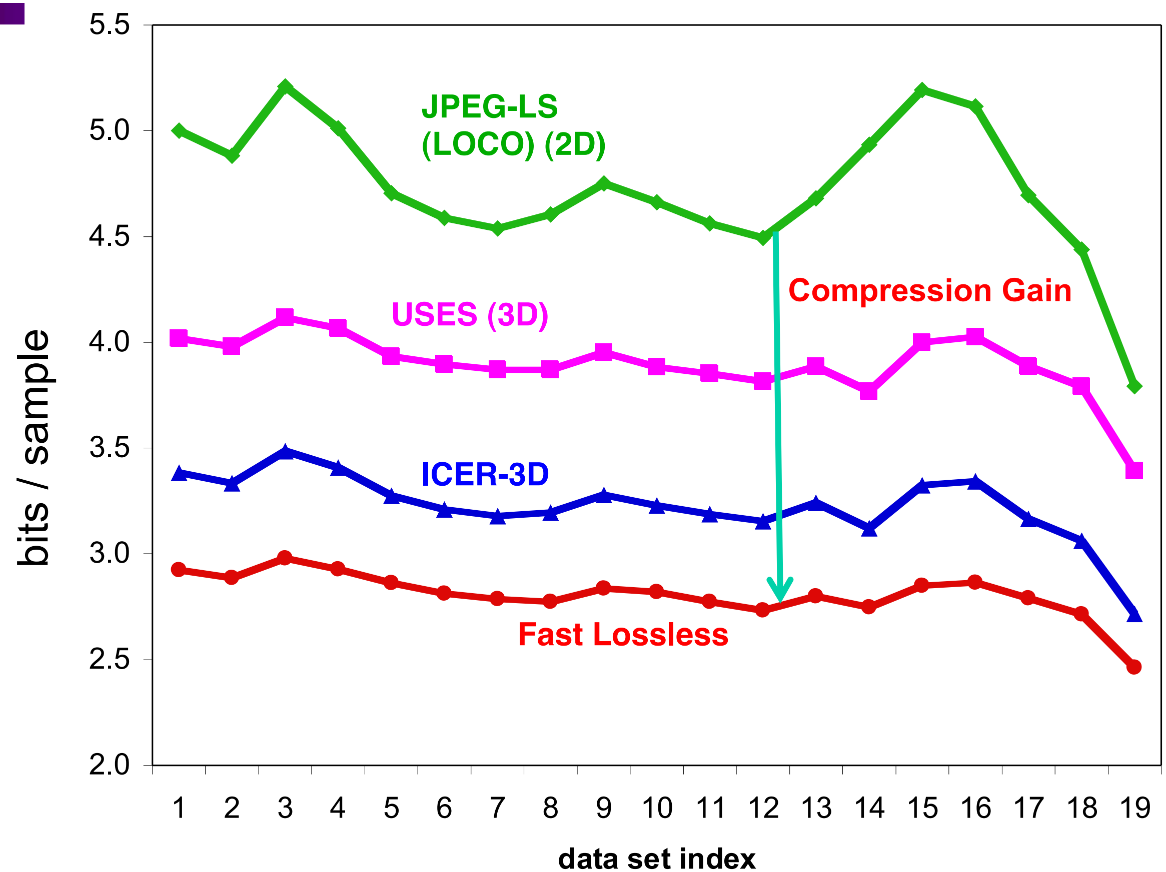
The *sign algorithm* and the *LMS algorithm* are members of a family of low complexity adaptive linear filtering techniques.

- Used extensively in signal processing applications
- Used for compression of audio data
- Not previously well studied for image or hyperspectral data compression

FL Compression Testing with AVIRIS-Classic



Comparison for raw AVIRIS Data



Compressor	rate (bits/ sample)
JPEG-LS (2D)	4.73
GSFC/USES Multispectral	3.89
ICER-3D	3.23
Fast Lossless	**2.81**

Compression performance averaged over 19 uncalibrated AVIRIS hyperspectral test data sets.

Tests using 19 uncalibrated AVIRIS data sets:

- original sample size: 12 bits/sample
- data size: (614 × 512 pixels × 224 bands)
  (680 × 512 pixels × 224 bands)

Methods:

JPEG-LS: is most efficient for 2D**; USES** uses chip; **ICER-3D** SOA (MER rovers)

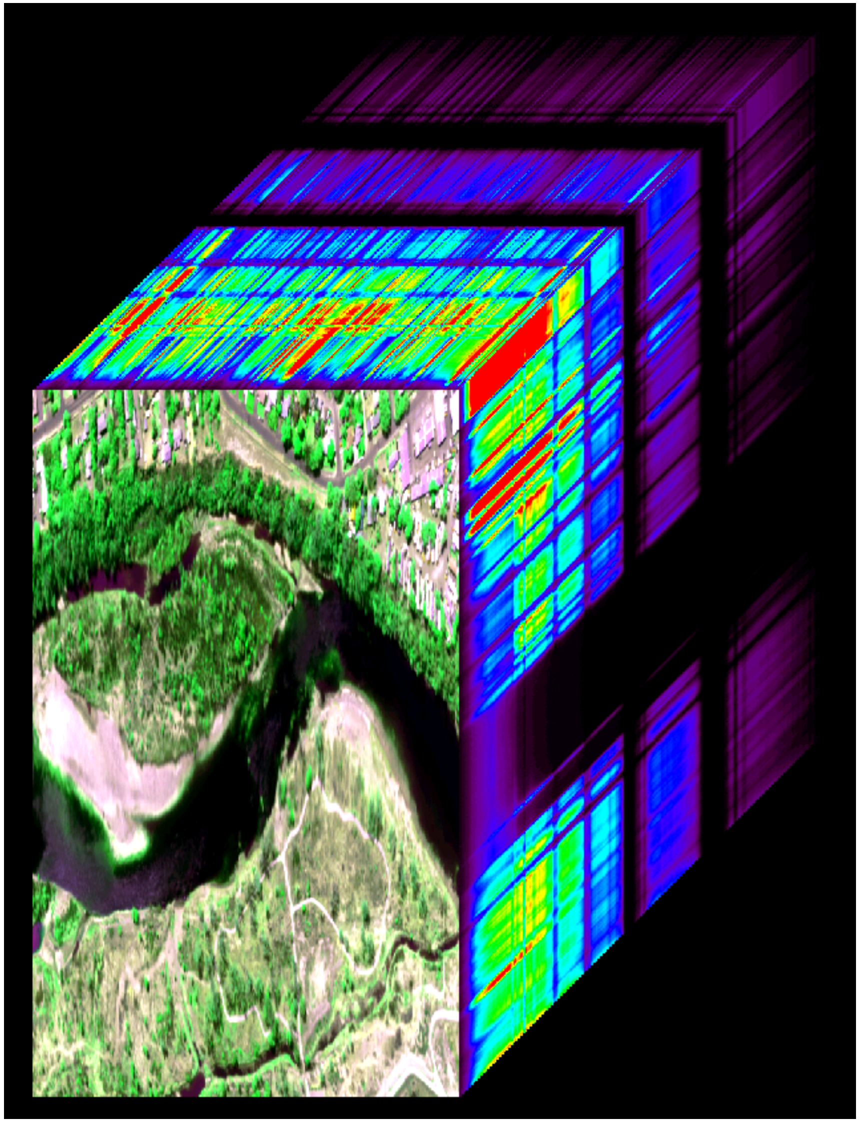
>4X compression.

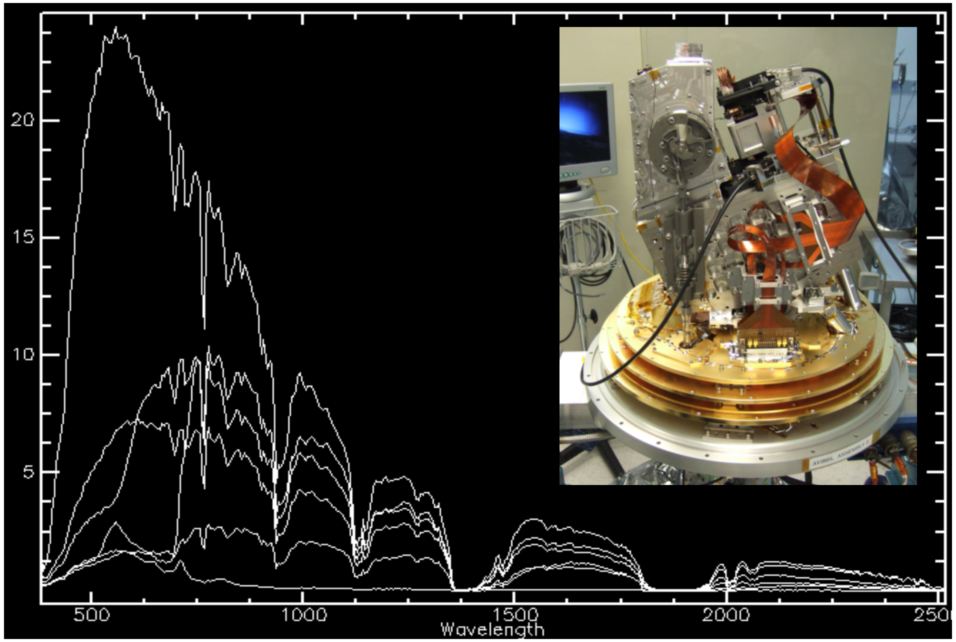
About 40% lower bit rate than state-of-the-art 2D approach.

FL Compression Algorithm Features

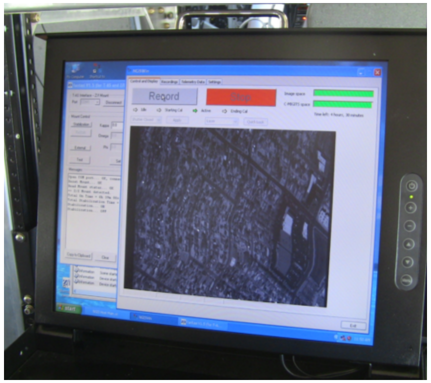
- **Performance:** good compression effectiveness
- **Robust**; requires no training data or other specific information about the nature of the spectral bands for a fixed instrument dynamic range
- **Simple**: well-suited for implementation on FPGA hardware and easily parallelizable
- **Low computational complexity**. required operations per sample are:
  - 6 integer multiplications
  - 25 integer addition, subtraction, or bit shift operations
  - Golomb coding operations
- **Modest memory requirement**: enough to hold one spatial-spectral slice of the data (e.g., ≤300 Kbytes for AVIRIS data with 224 bands and 680 samples/line)
- **Instrument**: well-suited to push broom instruments

AVIRIS Next Generation First Spectra 120422

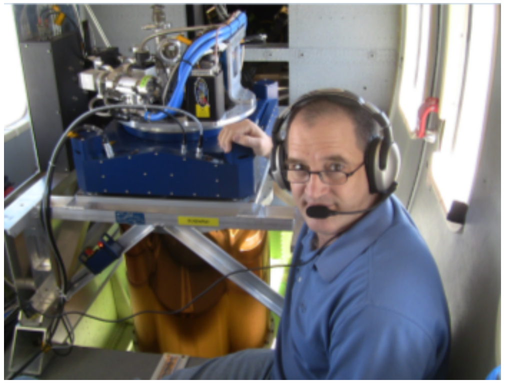




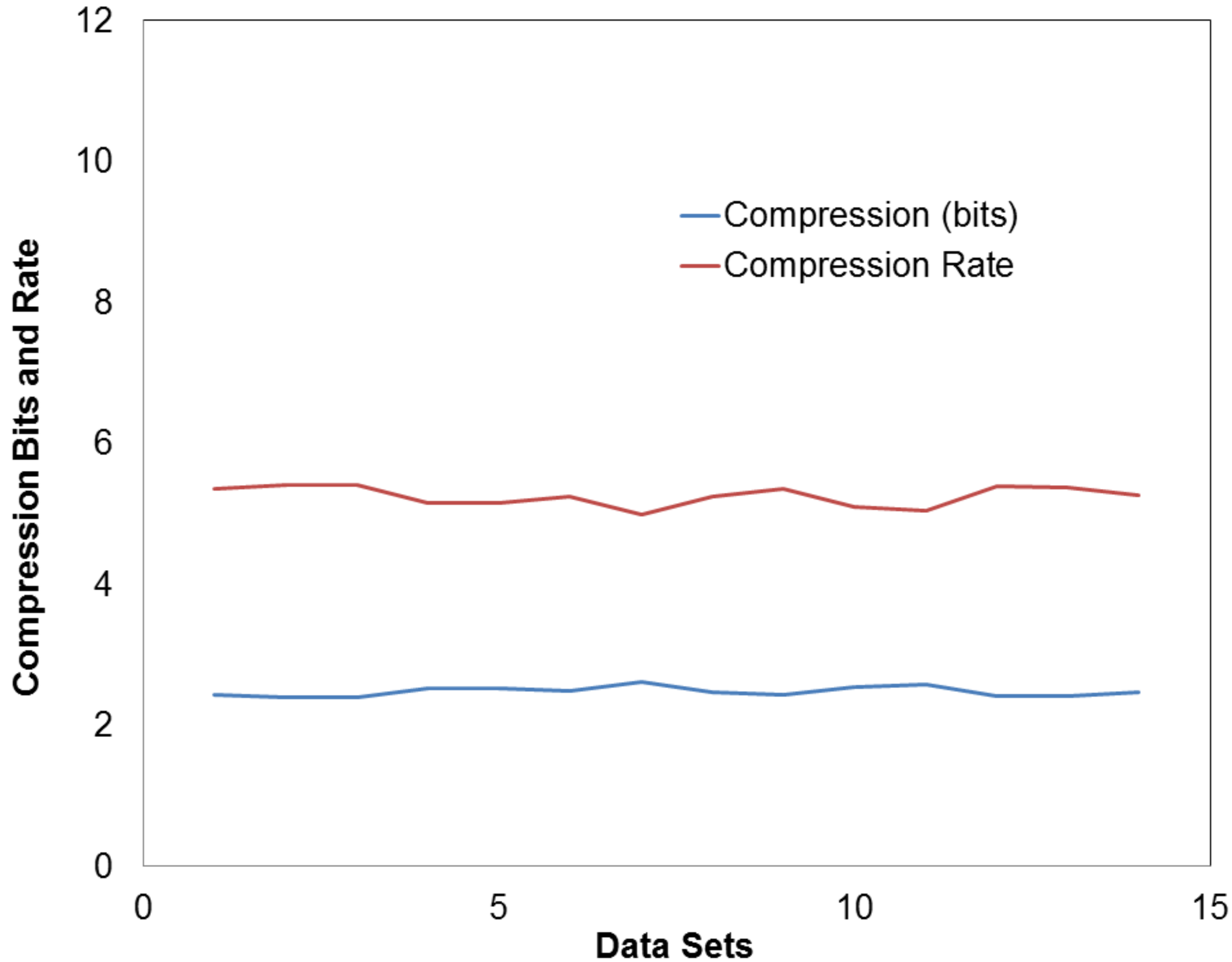
Scrolling Display



Michael Eastwood



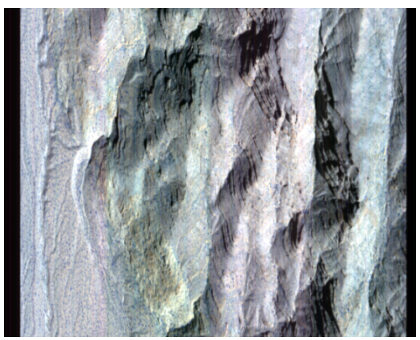
Early Test of AVIRIS-NG Like Data



- This test shows compression of > 5X
- HyspIRI baseline is 3X

Real-time Data Compression for HyspIRI

- Developed an FPGA implementation of the *Fast Lossless (FL), a* state-of-the-art lossless HSI compression algorithm providing compression performance up to 4:1.
- Implemented on a commercial Virtex 5 (equivalent to V5 Rad-hard device). Compresses one sample every clock cycle, a speed of 40 MSample/sec with total power of 700 mW.
- FL compression implementation is currently being tested in National Instruments PXI environment which includes a PXIe-7966R board with Xilinx Virtex-5 SX95T and two 256MBytes DRAMs. The test system is connected to the airborne AVIRIS-NG HSI instrument and will be compressing HSI data in real-time on the plane.

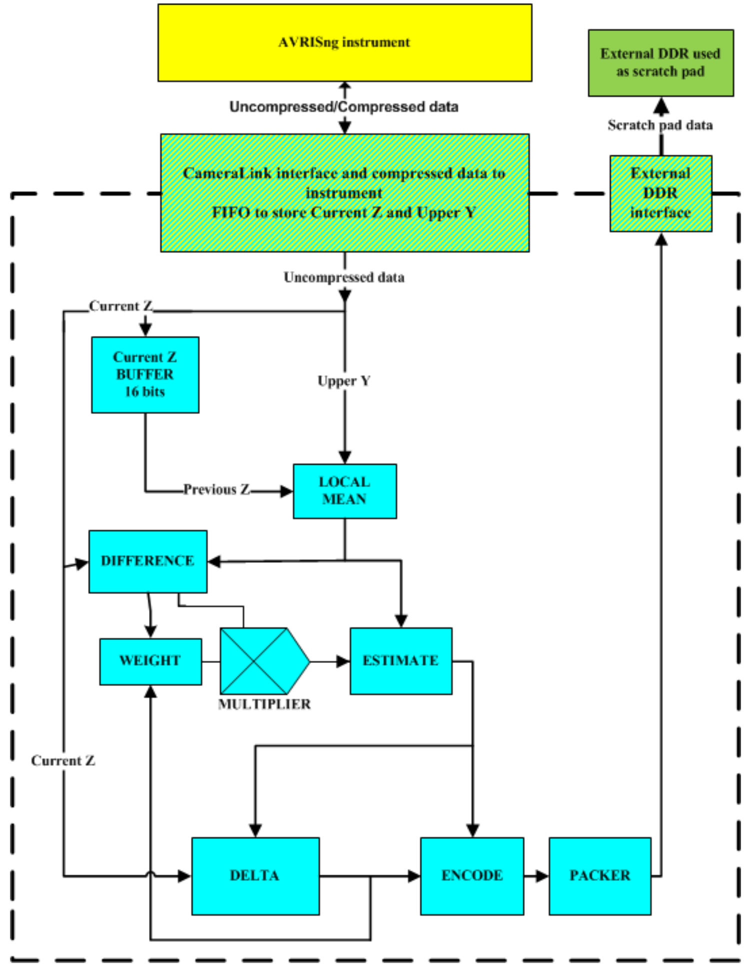


Carnegie Airborne Observatory:
A sample image
640(width) x 512(length) x 427(bands),
13 bits per sample
Compression rate: 2.366 bits/sample

PXIe-7966R Board with Xilinx Virtex-5 SX95T

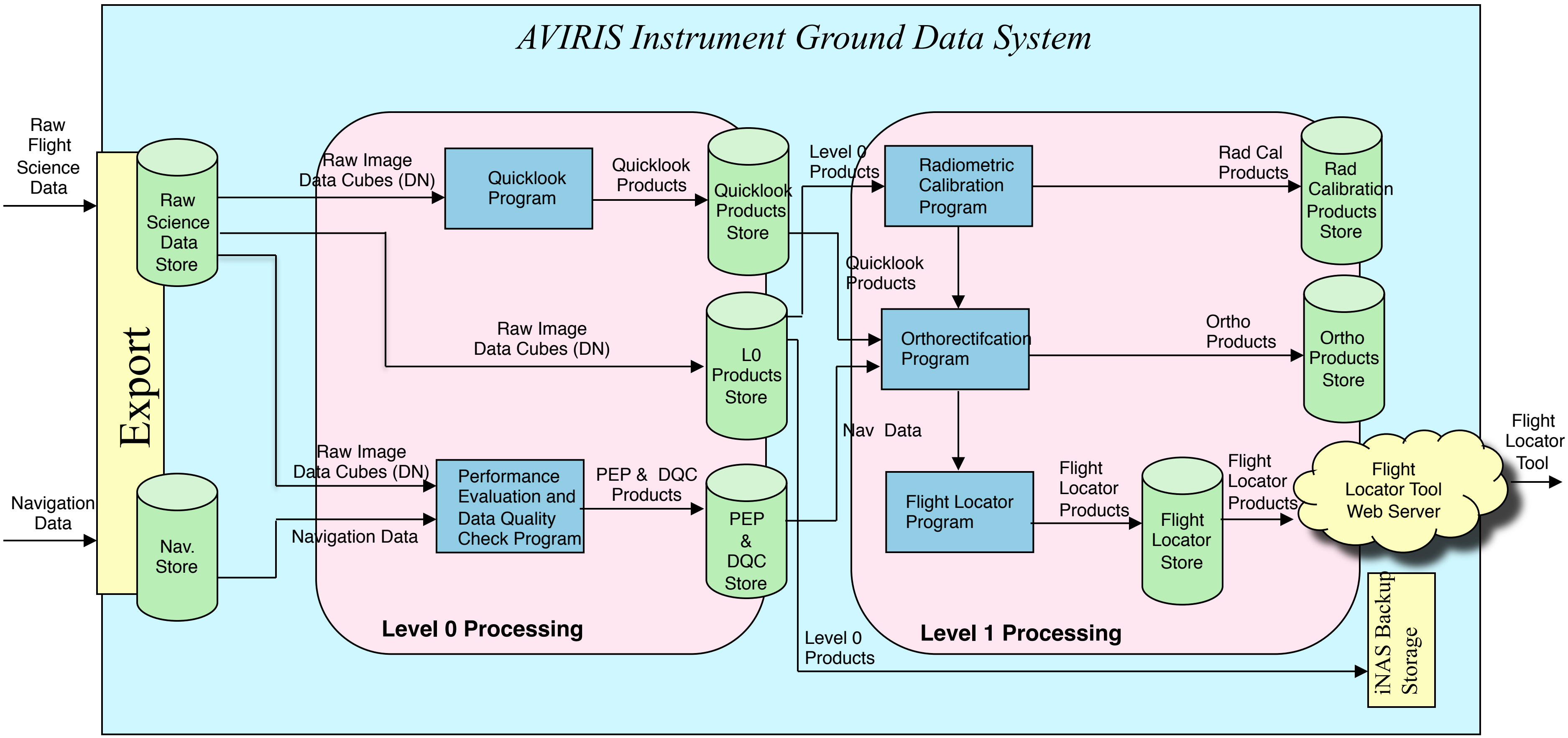
Virtex-5 Device Utilization Summary (CBE)

Logic Utilization	Used	Available	Utilization
# Slice Registers	15715	58880	26.7%
# Slice LUTs	24155	58880	41%
# Block RAM	76	244	31.1%
# DSP48s	6	640	0.9%



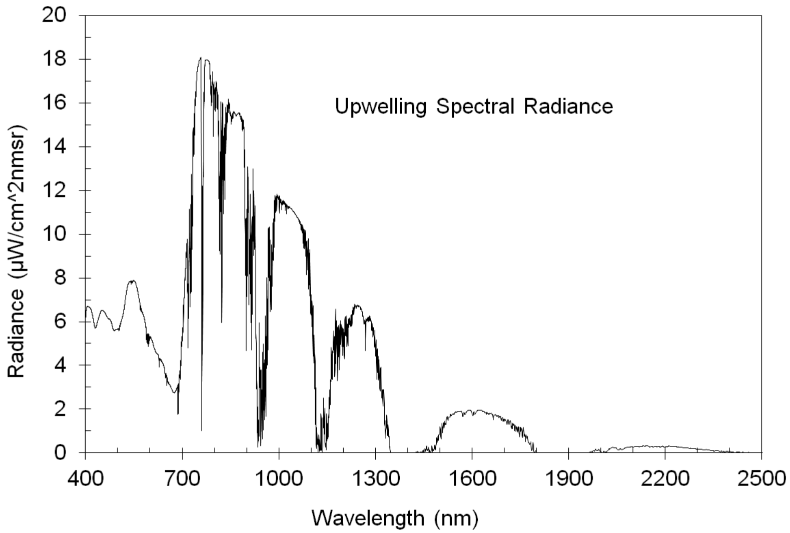
HyspIRI VSWIR Level 1 and 2 Algorithm Benchmarking

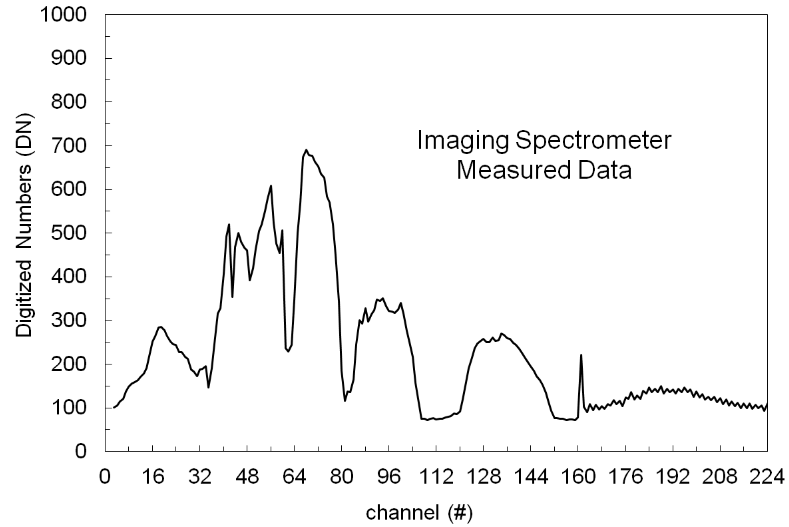
Level 0-1 AVIRIS-CL/AVIRIS-NG Data Flow

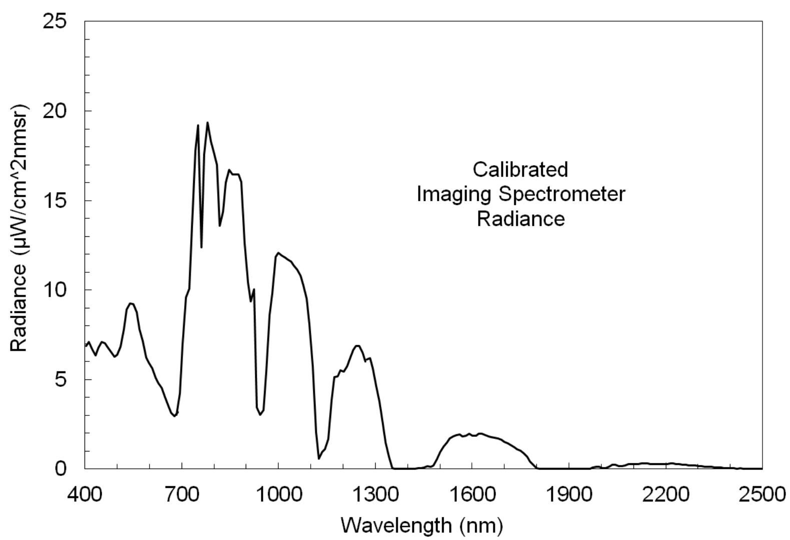


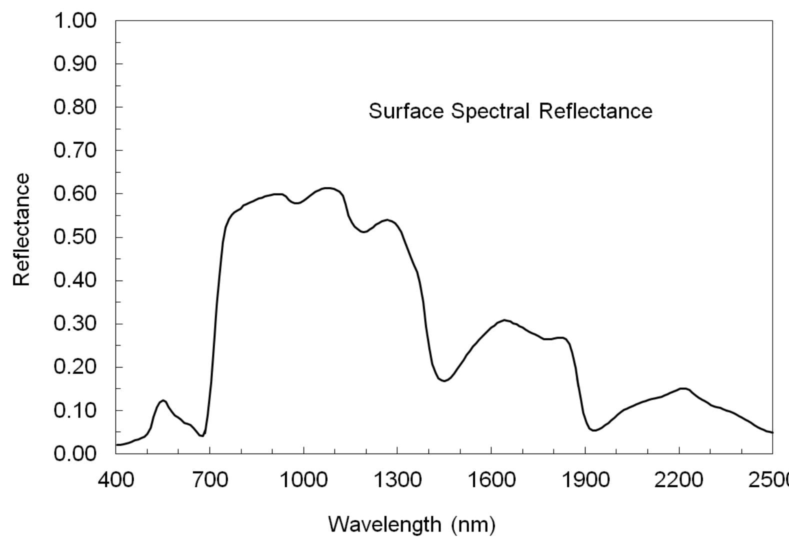
Manual Process | Automated Process | Product Generation Executive (PGE) | Data Products Store

Level 1 and Level 2 and The Signal









Atmospheric Correction

The measured radiance at the satellite level can be expressed as:

$$L_{obs} = L_a + L_{sun}\, t\, \rho \qquad (1)$$

L_a: path radiance;
ρ : surface reflectance;
L_{sun}: solar radiance above the atmosphere;
t: *2-way transmittance for the Sun-surface-sensor path*

Define the satellite apparent reflectance as

$$\rho^*_{obs} = \pi L_{obs} / (\mu_0 E_0) \qquad (2)$$

$$\rho^*_{obs} = T_g [\, \rho_a + t\, \rho / (1 - \rho\, s)\,] \qquad (3)$$

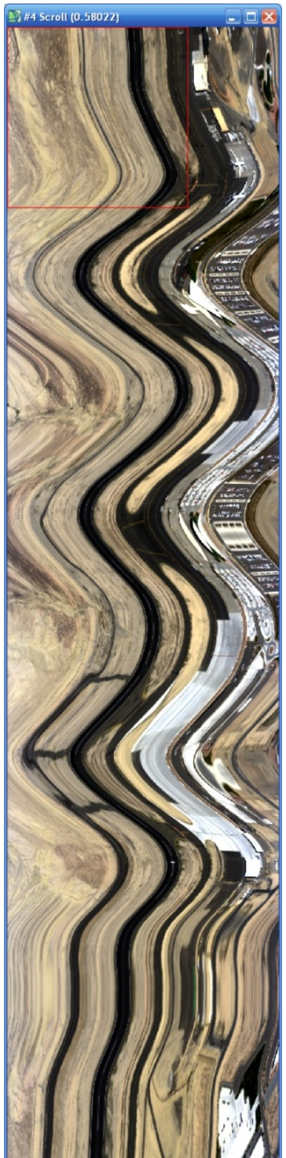
By inverting Eq. (3) for ρ, we get:

$$\rho = (\rho^*_{obs}/T_g - \rho^*_a) / [t + s\, (\rho^*_{obs}/T_g - \rho^*_a)\,] \qquad (4)$$

Gao, B.-C., K. H. Heidebrecht, and A. F. H. Goetz, Derivation of scaled surface reflectances from AVIRIS data, *Remote Sens. Env., 44*, 165-178, 1993.

AVIRIS-NG Orthorectification Test

Raw Data



Successful Orthorectification

AVIRIS-NG Orthorectified

HyspIRI VSWIR Level 1 and 2 Algorithm Prototyping –
Hardware Components of Windows 2008 Server

<u>Server</u>
•OS: 64-bit Windows Server 2008
•Processor: Dual Intel Xeon X5560 2.80GHz Quad-Core Processors
•Memory (RAM): 24.0 GB ECC DDR3

<u>Storage</u>
•4 RAID arrays populated with 24, 2TB 7200 RPM 64 MB Cache Enterprise Class SATA II HDD's
•4Gb Fibre Channel to SAS/SAS(SATA) Controller RAID Unit
•Total of 156 TB usable storage

<u>Backup Storage</u>
•iNAS 36 bay populated with (36) 4TB 7200 RPM 64 MB SATA II HDDs – Total 116 TB usable storage

HyspIRI VSWIR Level 1 and 2 Algorithm Benchmarking
AVIRIS-Classic

Data Set Type	Windows Server 2008	Beowulf Cluster – Single Node	Beowulf Cluster – 26 Nodes
AVIRIS-Classic	- Rad Cal: 353 GB in 761 min ➔7.9 MB/s - Ortho: 35.7 GB in 63 min ➔9.6 MB/s -ATREM: 732.6 GB in 1375 min ➔9.1 MB/s	- Rad Cal: 3.6 GB in 11 min ➔5.6 MB/s	- Rad Cal: 90.1 GB in 11.5 min ➔ 133.7 MB/s - Ortho: ~390 MB/s

HyspIRI VSWIR Level 1 and 2 Algorithm Benchmarking

Hardware Components of Beowulf Cluster

Traditional Beowulf Cluster - 27-node, 336 Processor Cores

<u>Head Node</u>
•OS: LinuCentOS 6.0
•Processor: (2) Intel Westmere E5650 2.66GHz, Hexa-Core Processors – Total of 12 cores
•Memory (RAM): (6) 8GB ECC DDR3 – Total 48GB
•Local Storage: (2) 1TB Mirrored HDD’ s – Total 1 TB usable storage

<u>Compute Nodes</u>
•OS: LinuCentOS 6.0
•Processor: (2) Intel Westmere E5650 2.66GHz, Hexa-Core Processors – Total of 12 cores
•Memory (RAM): (6) 8GB ECC DDR3 – Total 48GB
•Local Storage: (2) 1TB striped disks – Total 2 TB usable storage

<u>Storage Node</u>
•OS: LinuCentOS 6.0
•(16) 3TB enterprise server disks configured under RAID-6 array – Total 39TB usable storage after configuration
•Processor: (2) Quad-core Intel Westmere E5620 2.40GHz – Total 8 cores
•Memory (RAM): (6) 4GB ECC DDR3 – Total 24GB

<u>Backup Storage</u>
•iNAS 36 bay populated with (36) 4TB 7200 RPM 64 MB SATA II HDDs – Total 116 TB usable storage

HyspIRI VSWIR Level 1 and 2 Algorithm Benchmarking
AVIRIS-Next Generation

Data Set Type	Windows Server 2008	Beowulf Cluster – Single Node	Beowulf Cluster – 26 Nodes
AVIRIS-Next Generation	- Rad Cal: 13 GB in 96 min ➔2.3 MB/s - Ortho: 31.9 GB in 185 min ➔2.9 MB/s - ATREM: 33.6 GB in 79 min ➔ 7.3 MB/s	- Rad Cal: 110.83 GB in 179 min ➔10.6 MB/s - Ortho: 100.8 GB in 106.5 min ➔16.2 MB/s - ATREM: 31.9 GB in 62 min ➔8.8 MB/s	- Rad Cal: ~276 MB/s - Ortho: ~420 MB/s - ATREM: ~228 MB/s

HyspIRI VSWIR Level 1 and 2 Algorithm Benchmarking

Radiometric Calibration, Orthorectification, and ATREM Processing Speed

HyspIRI VSWIR daily uncompressed (at16 bits) data volumes:

- Minimum: 849 GB
- Mean: 1229 GB
- Maximum: 1436 GB

Estimated Processing Time of Uncompressed HyspIRI VSWIR using 26-node Beowulf Cluster			
Processing Algorithm	**Minimum Daily Rate**	**Mean Daily Rate**	**Maximum Daily Rate**
Radiometric Calibration	53 min	76 min	88 min
Orthorectification	34 min	50 min	58 min
ATREM	64 min	92 min	108 min
Total	151 min/2.5 hrs	218 min/3.6 hrs	254 min/4.2 hrs

Summary and Conclusion

- HyspIRI VSWIR data rates and volumes are high by current standards and could represent a risk to implementation and cost estimates.

- The HyspIRI Mission concept team has be testing algorithms and implementation approaches to demonstrate the validity of the HyspIRI Mission concept

- The on-board VSWIR FL compression algorithm is now being tested in the flight like FPGA implementation

- HyspIRI analog ground Level 1 and Level 2 data processing algorithms are being tested with AVIRIS-Classic and AVIRIS-Next Generation data sets

- Scaling these benchmarking results shows that the HyspIRI mission concept is viable for on-board compression and ground processing of Level 1 and Level 2.

- There may be options for improved implementation margins and reduced costs in the HyspIRI mission concept in these areas

HyspIRI Decadal Survey Mission

Key Science and Science Applications

Climate: Ecosystem biochemistry, condition & feedback; spectral albedo; carbon/dust on snow/Ice; biomass burning; evapotranspiration

Ecosystems: Global plant functional-type, physiological condition, and biochemistry including agricultural lands.

Fires: Fuel status, fire occurrence, severity, emissions, and patterns of recovery globally.

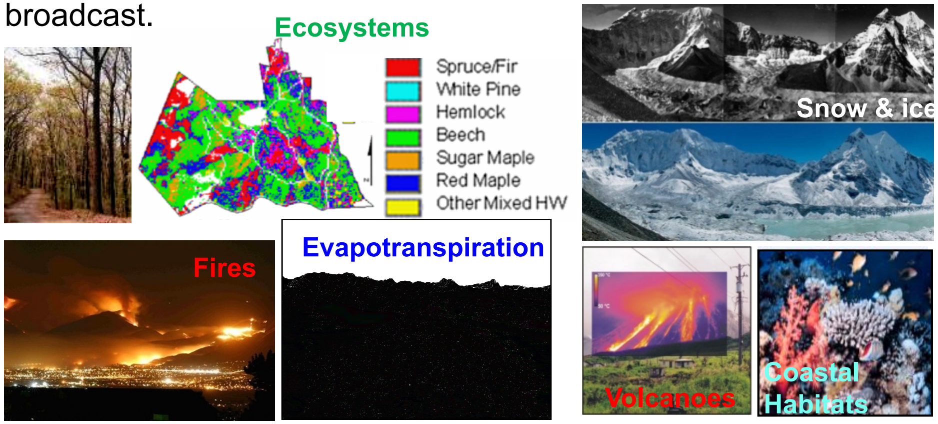
Coral reef and coastal habitats: Global composition and status.

Volcanoes: Eruptions, emissions, regional and global impact.

Geology and resources: Global distributions of surface mineral resources and improved understanding of geology and related hazards.

Mission Urgency:

The HyspIRI science and application objectives are important today and uniquely addressed by the combined imaging spectroscopy, thermal infrared measurements, and IPM direct broadcast.



Measurement:

Imaging Spectrometer (VSWIR)

- 380 to 2500 nm in 10nm bands
- 60 m spatial sampling
- 19 days revisit

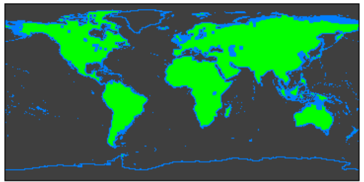
-Global land and shallow water

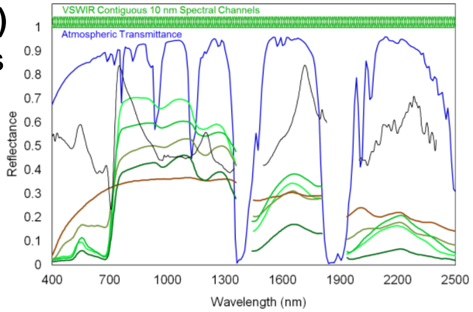
Thermal Infrared (TIR):

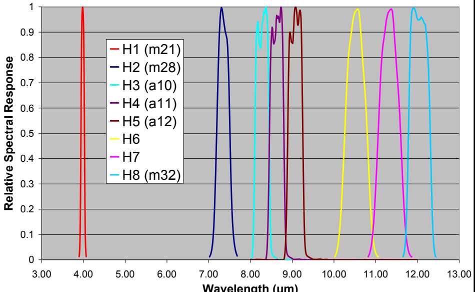
- 8 bands between 4-12 µm
- 60 m spatial sampling
- 5 days revisit

-Global land and shallow water

IPM-Direct Broadcast







Mission Concept Status:

Preliminary Draft Program Level 1 Requirements: Stable

Payload: Imaging Spectrometer, Thermal Infrared Imager, and IPM-Direct Broadcast subset

Spacecraft: Small

Payload: JPL/GSFC

Launch Vehicle: ~1000 kg class

Launch date: TBC (partner opportunitie

Mission: Class C 3-5 years

Trajectory or Orbit: LEO, Sun sync.

S/C & Instrument Mass: 561 kg (30% margin)

S/C & Instrument Power: 650W (66% margin)

The HyspIRI mission concept is mature and stable with excellent heritage, low risk and modest cost.

Backup

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