Section 2

Hyperion, ALI, and the EO-1 Mission

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NASA GSFC, Code 923

Darla M. Duval
USGS/Raytheon ITSS/EROS DataCenter
EO-1 Mission Facts

ORBIT

705 Km altitude Sun-synchronous, circular orbit inclined at 98.2°
Descending node with an equatorial crossing about one minute behind Landsat 7

LAUNCH

Launch Date: Nov. 21, 2000
Launch Vehicle: Delta 7320
Co-manifested with SAC-C

ADVANCED LAND IMAGER (ALI)
Multispectral Pushbroom Imager

HYPERION
Hyperspectral Imaging Spectrometer

ATMOSPHERIC CORRECTOR (AC)
Wedge Imaging Spectrometer

Wide-band Advanced Recorder / Processor

X-Band Phased Array Antenna

C&DH S-Band Antenna

WW ADVANCED RR Recorder / Processor

Hyperion & ALI Data Users Workshop
EO-1 & Landsat

Landsat ETM+ Multispectral Swath Coverage (185 km @ 30 m)

ALI Multispectral Swath Coverage (37 km @ 30 m)

Atmospheric Corrector Hyperspectral Coverage (185 km @ 125 / 250 m)

AVIRIS Underflight (10 km @ 20 m)

Hyperion Hyperspectral Swath Coverage (7.7 km @ 30 m)

705 km Altitude
EO-1 & Landsat 7
Descending Orbit Ground Tracks

Landsat 7 ETM+

EO-1 Atmospheric Corrector

EO-1 Hyperion (7.7 KM)

EO-1 ALI

(37 KM)

(185 KM)
EO-1 Flight Instruments

ADVANCED LAND IMAGER (ALI)

HYPERION

ATMOSPHERIC CORRECTOR (AC)
### EO-1 Instrument Overviews

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Landsat 7 ETM+</th>
<th>EO-1 ALI Multispectral</th>
<th>EO-1 Hyperion</th>
<th>EO-1 AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Range</td>
<td>0.4 - 2.4 µm*</td>
<td>0.4 - 2.4 µm</td>
<td>0.4 - 2.5 µm</td>
<td>0.9 - 1.6 µm</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>30 m</td>
<td>30 m</td>
<td>30 m</td>
<td>250 m</td>
</tr>
<tr>
<td>Swath Width</td>
<td>185 Km</td>
<td>37 Km</td>
<td>7.5 Km</td>
<td>185 Km</td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>Variable</td>
<td>Variable</td>
<td>10 nm</td>
<td>3 - 9 nm **</td>
</tr>
<tr>
<td>Spectral Coverage</td>
<td>Discrete</td>
<td>Discrete</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td>Pan Band Resolution</td>
<td>15 m</td>
<td>10 m</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Total Number of Bands</td>
<td>7</td>
<td>10</td>
<td>220</td>
<td>256</td>
</tr>
</tbody>
</table>

* Excludes thermal channel
** 35/55 cm\(^{-1}\) constant resolution
ALI Description

@ 5% Earth Surface Reflectance

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength (nm)</th>
<th>Band</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pan</td>
<td>480-690</td>
<td>MS-4</td>
<td>775-805</td>
</tr>
<tr>
<td>MS-1′</td>
<td>433-453</td>
<td>MS-4′</td>
<td>845-890</td>
</tr>
<tr>
<td>MS-1</td>
<td>450-515</td>
<td>MS-5′</td>
<td>1200-1300</td>
</tr>
<tr>
<td>MS-2</td>
<td>525-605</td>
<td>MS-5</td>
<td>1550-1750</td>
</tr>
<tr>
<td>MS-3</td>
<td>630-690</td>
<td>MS-7</td>
<td>2080-2350</td>
</tr>
</tbody>
</table>
ALI Focal Plane Assembly
MS/PAN Flight Module
Solar Calibration

<table>
<thead>
<tr>
<th>Signal Level</th>
<th>Cumulative Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>7%</td>
<td>10%</td>
</tr>
<tr>
<td>20%</td>
<td>30%</td>
</tr>
<tr>
<td>20%</td>
<td>50%</td>
</tr>
<tr>
<td>20%</td>
<td>70%</td>
</tr>
<tr>
<td>20%</td>
<td>90%</td>
</tr>
</tbody>
</table>

Aperture Selector

Diffuser

Solar Beam

Secondary

Cover

Scattered Light

Solar Calibration Profile

Counts

Frame Number
**Landsat Instrument Comparison**

**ALI Based Concept for Future Landsat Instrument**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>425</td>
</tr>
<tr>
<td>Power (W)</td>
<td>545</td>
</tr>
<tr>
<td>Size (m³)</td>
<td>1.4</td>
</tr>
<tr>
<td>Size (cm)</td>
<td>196x114x66</td>
</tr>
<tr>
<td>VNIR / SWIR Bands</td>
<td>7</td>
</tr>
<tr>
<td>Detectors Per Band</td>
<td>16</td>
</tr>
<tr>
<td>Thermal Bands</td>
<td>1</td>
</tr>
<tr>
<td>Data Rate (Mbps)</td>
<td>150</td>
</tr>
<tr>
<td>Pan Resolution (m)</td>
<td>15</td>
</tr>
<tr>
<td>Relative SNR</td>
<td>1</td>
</tr>
</tbody>
</table>

**Enhanced Thematic Mapper (ETM+)**
# EO-1 Instrument Overviews

<table>
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<tr>
<th>Parameters</th>
<th>Landsat 7 ETM+</th>
<th>EO-1 Multispectral</th>
<th>EO-1 HYPER D N</th>
<th>AC</th>
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* Excludes thermal channel
** 35/55 cm⁻¹ constant resolution

Hyperspectral Analysis derives from the use of contiguous spectral channels, allowing the use of derivatives and sophisticated analysis techniques. The large number of bands allows more complex systems to be addressed without the under sampling inherent in multispectral systems.
Hyperion S/N Performance

- Radiometric performance model based on 60° Solar zenith angle and 30% surface reflectance standard mid-latitude summer scene.

<table>
<thead>
<tr>
<th>Wavelength (µm)</th>
<th>Hyperion Measured SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>550 nm</td>
<td>161</td>
</tr>
<tr>
<td>650 nm</td>
<td>144</td>
</tr>
<tr>
<td>700 nm</td>
<td>147</td>
</tr>
<tr>
<td>1025 nm</td>
<td>90</td>
</tr>
<tr>
<td>1225 nm</td>
<td>110</td>
</tr>
<tr>
<td>1575 nm</td>
<td>89</td>
</tr>
<tr>
<td>2125 nm</td>
<td>40</td>
</tr>
</tbody>
</table>
Convex Grating spectrometers with CCD VNIR and HgCdTe SWIR detectors (60µm pixels)

30m spatial and 10nm spectral resolutions over 7.5km swath and 400-2500nm spectral range

Multiple calibration options: lamps, lunar, solar, ground imaging and laboratory

Hyperspectral Imaging Capability to address Earth Observation applications
Hyperion Optical System

Grating Spectrometer

Telescope
Hyperion Subsystems

Hyperion Electronics Assembly

Cryocooler Electronics Assembly

Hyperion Sensor Assembly (HSA)
## Signal-to-Noise (Source TRW)

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>SNR Requirement</th>
<th>On-Orbit Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>550</td>
<td>&gt;60</td>
<td>192</td>
</tr>
<tr>
<td>650</td>
<td>&gt;60</td>
<td>140</td>
</tr>
<tr>
<td>700</td>
<td>&gt;60</td>
<td>140</td>
</tr>
<tr>
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<td>&gt;60</td>
<td>65</td>
</tr>
<tr>
<td>1225</td>
<td>&gt;60</td>
<td>96</td>
</tr>
<tr>
<td>1575</td>
<td>&gt;60</td>
<td>64</td>
</tr>
<tr>
<td>2125</td>
<td>&gt;30</td>
<td>38</td>
</tr>
</tbody>
</table>
SNR Calculated From Solar Calibration Data

SWIR Noise Characteristics

VNIR Solar counts v. noise

flux (DN)
Scene Based Estimate of Hyperion SNR
(Source JPL AVIRIS LAB)
# EO-1 Scene Tracking Statistics

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Scheduled Scenes</td>
<td>2047</td>
</tr>
<tr>
<td>Scenes Successfully Downlinked</td>
<td>1626</td>
</tr>
<tr>
<td>Level-0 Data Processed</td>
<td>1881</td>
</tr>
<tr>
<td>Total Scenes Shipped to PIs</td>
<td>1571</td>
</tr>
</tbody>
</table>

As of COB 10/24/01
Science Validation Team

- **Instrument Team**
  - Validate/re-establish and refine pre-launch characterizations
  - Provide technology validation
  - Participate on Science Validation Team

- **NASA Selected Investigators**
  - Conduct scene based instrument performance characterizations
  - Measure ability of instruments to make Landsat-like observations
  - Assess capability for addressing earth remote sensing applications
  - Assist in technology validation
  - Facilitate Commercial Applications (CRSP/SSC)

- **International Collaborators**
  - Argentina, Australia, Canada, Italy, Japan, Singapore
“First Light” Image of Alaska

L7 PAN

ALI PAN
Why is the ALI pan band better than the ETM+ pan band?

- **Improved Radiometric resolution**
  - Superior signal-to-noise
  - 12-bit versus 8-bit representation of dynamic range

- **Inherently higher contrast measurement**
  - ALI pan restricted to 480 – 690nm VIS spectral interval
  - ETM+ spans vegetation transition rise (520 – 900nm)

- **Smaller pixel size (IFOV)**
  - ALI pan IFOV is 10 meters
  - ETM+ is nominally 15 meters (effectively 18 meters)
EO-1/ALI and IKONOS Comparison

ALI Pan Enhanced 4-3-2 Composite
Washington DC, December 1, 2000

IKONOS MS 4-3-2 Composite
Washington DC, April 1, 2000
Area of First Hyperion Image Collection (Green Square)
Hyperion Image - Argentina

Hyperspectral DCE Acquired Dec 1, 2000
Color image produced using 3 bands in visible
   Blue = band 14 (488 nm)
   Green = band 20 (549 nm)
   Red = band 38 (731 nm) (red shows areas of new spring growth)

Image No. EO12000336_002002C_r1_image0su
Approx. 7.5 km wide x 65 km long
← NORTH
Hyperion Image taken near Washington DC (Fairfax, VA) on Friday December 1, 2000

The image shown to the right, taken by the Hyperion Imaging Spectrometer on EO-1, reveals the relative chlorophyll content of vegetation in an area of Fairfax County, Va. The spectral profiles indicate healthy grass in the stadium field and golf course. The spectral profile of the trees indicates dormant vegetation.

Oxygen in the atmosphere is detected at near infrared wavelengths in the spectral profiles.

Courtesy of TRW Inc.
Sample Hyperion Images

Blythe
Day 007

San Francisco
Salt Ponds
Day 017
LAC Image (1.26µm)

Tumbarumba, Australia (Lake Hume in center)

December 25, 2000

February 12, 2001
Advanced Land Imager
Color Composite

R = Band 4
G = Band 3
B = Band 2
Oahu
December 19, 2000

Image of Hyperion VNIR and SWIR bands

R= 2200 nm
G= 850 nm
B= 1680 nm

Spectrally aggregated Hyperion bands

R= 2100-2300 nm
G= 750-900 nm
B= 1550-1750 nm
Eldorado, Argentina
You can’t do that with EO-1!
(Views with the EO-1 ALI Pan band)
Out of this World Calibration

Lunar image provides direct-viewing radiometric measurements for calibration without atmospheric effects.

Issues of the lunar model and analysis techniques are being addressed

Courtesy of P. Barry & H. Kieffer
You can’t do that with EO-1!
(Views with the EO-1 ALI Pan band)

The Pleiades

ALI detections
Special Hyperion Characterization Targets

Searchlights
-California

Planets
-Venus

Gas Flares
-Moomba

90 deg Yaw
Vostok Base, East Antarctica
Vostok Base, East Antarctica
Lingshui Airfield 04/10/01

ALI Pan Band
Lingshui Airfield 04/10/01

ALI Pan Band
Lingshui Airfield 04/10/01

ALI Pan Band

I can’t tell you!
“The Strip”
Las Vegas
Nevada
3-2-1 ALI Composite
Mount Etna - July 22, 2001

ALI Pan Enhanced 3-2-1

EO-1 ALI Bands 7-5-5’
SNR Calculated From Solar Calibration Data

SWIR Noise Characteristics

- Even
- Odd

Average DN vs. Noise

VNIR Solar counts v. noise

Flux (DN) vs. Noise
Scene Based Estimate of Hyperion SNR

Wavelength (nm)

Mean/StdDev for Cal site ROI

400 700 1000 1300 1600 1900 2200 2500
Topics

- Extended Mission Approach
- Operations Overview
- Organizational Responsibilities
- EO-1 Products available from USGS
- Data and Pricing Policy
- USGS Project POCs
Extended Mission Approach

- Phased transition from technology mission to operational
- Products become publicly available
- Operations cost fully reimbursable
- Manual processes initially; automated over time
- Transfer of processing equipment and scheduling responsibilities to EDC underway
- Archive / catalog of 1st year of acquisition data being built
- Data Acquisition Requests (DARs) will be taken for new acquisitions
- At EROS Data Center (EDC) starting mid-December 2001
Operations Overview

- Mission Operations Center
- Planning & Tasking
- User Services (DAR and archive orders, payment)
- Product Distribution Server
- EDC Data Capture
- NASA Data Capture
- Data Processing (ALI L0 and L1, Hyperion L0)
- Hyperion L1 processing
- EDC Archive
- WWW Site
- Customer

Legend:
- NASA
- USGS
- TRW
Organizational Responsibilities

Earth Observing-1
Hyperion & ALI Data Users Workshop

Nov. 28-29, 2001

NASA Integrated Services Network (NISN)

Mission Operations Center (MOC) at GSFC
• Core Ground System (CGS)
  • Command and control
  • Health and Safety monitoring
  • Trending
  • Command Management Sys
  • S-Band Science Data Processing
  • Sensor Calibrations
• Mission Ops Planning & Scheduling System (MOPSS)
  • Planning and Scheduling
• Flight Dynamics System (FDS)
  • Orbit
  • Attitude

Legend
• NASA
• USGS
• TRW
• Australia

• Customer Web Site Interface
• Catalog Query
• ALI/Hyperion Order Interface
• Acquisition Planning
• ALI Processing/Distribution - L0/L1
• Hyperion Distribution - L0/L1
• DPS Processing - ALI/Hyperion L0
• Archive Hyperion/ALI L0/L1 data
• Billing/Accounting/Financial Mgmt
• Customer Technical Support

• Customer Queries, Orders, Payments
• Product Deliveries to Customers

• X-band DLT Tapes
• USGS EDC 5.4M System
• Hobart, AU Ground Station

• X and S Band Playback
• Real-time Telemetry Command

• TRW
  • Process Hyperion to L1

• NASA Polar GN
• TDRSS/WSC

• Real-time Backup Support
• X and S Band Playback
• Real-time Telemetry Command

• X-Band DLT Tapes

• TRW
  • Process Hyperion to L1

• Landsat 7 State Vectors
• Formation Flying Coordination

• Landsat 7 MOC at GSFC

• Doppler Angles
• WARP Playback State of Health

• Tables
• Memory Loads
• Commands
• Landsat 7 State Vectors

• RT State of Health
• Playback SOH
• Post Pass Analysis
• Significant Events

TRW

Customer Queries, Orders, Payments
Product Deliveries to Customers
EO-1 Products

† Archived Products

† Data Acquisitions Requests (DARs) and Products

† ALI L1
  – Radiometrically corrected, HDF
  – Footprint 37-km across track by 42-km (TBD) along-track
  – 4 separate detector array files

† Hyperion L1B
  – Radiometrically corrected, HDF, 16-bit signed, band interleaved, SWIR and VNIR referenced to each other
  – Footprint 7.7-km across track by 42-km (TBD) along-track

† FTP pull, CD, DVD media

† Product reformatting to more user friendly eventually

† L0 data is archived; used only to reprocess L1 products

† Turnaround time initially 48 hours from availability of data at EDC, work to 5 hrs (expedited)
Data and Pricing Policy

† Data in the Public Domain
  – Holdback restrictions may apply for acquisitions (TBD)

† Pricing
  – DAR for 1st sensor = $1500
  – DAR for 2nd sensor (same data collection event) = $300
  – Product from archive = $500 (working to be lower)
    (regardless of geographic coverage area)
  – New DAR products = $700
    – 42-km (TBD) along track strip
    – Different, longer length along-track pricing TBD

† Policy regarding cloud cover and multiple orders for same acquisition product TBD
USGS Project POCs

† **Data pricing and policy**

  – **John Boyd**
  – **USGS Satellite System Initiatives Program Manager**
  – [Boyd@usgs.gov](mailto:Boyd@usgs.gov) 605-594-6163

† **User Interface**

  – **Darla Duval**
  – **Raytheon ITSS**
  – [DDuval@usgs.gov](mailto:DDuval@usgs.gov) 605-594-6993