2016 Mission Operations Working Group
Earth Observing-1 (EO-1)

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Code 581 Software Systems Engineering Branch

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Hyperion (red) overlay on ALI Image (green), Oct 2012 Baltimore, MD

Hyperion Spectral Response

ALI False-Color Image, 2014 San Miguel Volcano
ALI True-Color Image, 2013 Bird Sanctuary in India
ALI False-Color Image, 2013 Fire in Australia
EO-1 Complementing Landsat 8 and MODIS

When the Villarrica Volcano erupted, EO-1 was able to acquire an image on March 5, 2015 – five days before the next Landsat 8 overpass.

EO-1 ALI night-time image of the Vatnajokull volcano complementing MODIS (top).

ALI natural-color composite August 27 overlaid with an infrared (IR) night view from September 1, 2014.

EO-1 ALI complementing OLI. When the Villarrica Volcano erupted, EO-1 was able to acquire an image on March 5, 2015 – five days before the next Landsat 8 overpass.
EO-1 image of Wolf Volcano in Galapagos
Eruption on May 25th, image acquired on May 28th

EO-1 ALI night-time image of Holuhraun Iceland volcano
On January 1, 2016, Hyperion imaged the massive methane leak in the Aliso Canyon region of California. David Thompson’s (JPL) algorithm detected the methane leak within the Hyperion data and showed a pronounced plume trending to the south. Since then, six additional acquisitions have been made, thanks to EO-1’s ability to rapidly schedule, reorient satellite attitude, and quickly process and distribute the data.
2016 Flooding on the Mississippi River
## EO-1 Phase F Decommissioning Timeline

<table>
<thead>
<tr>
<th>Mission Operations, Science and Decommissioning Timeline</th>
<th>Beginning Date of Activity</th>
<th>Duration</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Science Activities</strong></td>
<td></td>
<td></td>
<td><strong>Selected Key Activities</strong></td>
</tr>
<tr>
<td>Generate Level 2 Reflectance</td>
<td></td>
<td></td>
<td>Provided on demand, improvements for water and diverse terrain</td>
</tr>
<tr>
<td>Prototype Land Cover Products</td>
<td>10/1/16</td>
<td>1 year</td>
<td>For HyspIRI, NASA TE, C Cycle and Climate Change, Bio-physical variables (Veg. fraction, pigments, LAI, moisture, Albedo)</td>
</tr>
<tr>
<td>Support NASA SLI and NEW Satellite Missions</td>
<td></td>
<td></td>
<td>Data fusion and prototype products (ALI, Hyperion, Landsat, SENTINEL 2 MSI)</td>
</tr>
<tr>
<td>Spectral time series for VEGETATION targets</td>
<td></td>
<td></td>
<td>FLUX sites, instrumented sites (e.g. SpecNet, LED), LTER, etc.</td>
</tr>
<tr>
<td>Spectral time series for CAL/VAL targets</td>
<td></td>
<td></td>
<td>CEOS PICS, VIS/NIR sensor intercomparison</td>
</tr>
<tr>
<td><strong>Disaster Response and Mitigation</strong></td>
<td>12/31/16</td>
<td></td>
<td>Relief efforts- floods, hurricanes, fires, volcanoes</td>
</tr>
<tr>
<td><strong>Decommissioning Timeline</strong></td>
<td></td>
<td></td>
<td>From receipt of termination notice to total close-out of EO-1 mission</td>
</tr>
<tr>
<td>Receive direction for NASA HQ to begin termination process flow</td>
<td>8/31/16</td>
<td>1 day</td>
<td>Initial trigger to begin proposed steps below</td>
</tr>
<tr>
<td>Update End of Mission Plan &amp; develop decommissioning plan</td>
<td>9/30/16</td>
<td>30 days</td>
<td>As the mission is closer to a baseline EOMP, Final EOMP and Decommissioning Plan will require less time to be completed</td>
</tr>
<tr>
<td>Notification of Intent to Terminate is sent to Administrator with updated EOMP</td>
<td>10/1/16</td>
<td>1 day</td>
<td>Per NASA Policy Directive NPD8010.3B Notification of Intent to Decommission or Terminate Operating Space Systems and terminate Missions</td>
</tr>
<tr>
<td>Prepare for Decommission Review</td>
<td>11/15/16</td>
<td>45 days</td>
<td>Days from Intent to Terminate Notification</td>
</tr>
<tr>
<td>Decommission Review</td>
<td>11/16/16</td>
<td>1 day</td>
<td>This is KDP-F #1</td>
</tr>
<tr>
<td>HQ authorizes decommissioning &amp; termination</td>
<td>11/23/16</td>
<td>5 days</td>
<td>Allowing HQ to make decision 5 days following Decommissioning Review</td>
</tr>
<tr>
<td>Passivation Simulation and Rehearsals</td>
<td>12/15/16</td>
<td>25 days</td>
<td>Days from Intent to Terminate Notification</td>
</tr>
<tr>
<td>EO-1 Key Decision Point – Phase F</td>
<td>12/15/16</td>
<td>30 days</td>
<td>Days from Decommission Review</td>
</tr>
<tr>
<td>Wait a minimum of 90 days following Notification of Intent to Terminate</td>
<td>1/1/17</td>
<td>90 days</td>
<td>Per NASA Policy Directive NPD8010.3B Notification of Intent to Decommission or Terminate Operating Space Systems and terminate missions</td>
</tr>
<tr>
<td>Perform Pulse Plasma Thruster Test with all instruments ON to assess contamination</td>
<td>1/12/17</td>
<td>7 days</td>
<td>Could consider performing prior to HQ authorization to decommission at KDP-F</td>
</tr>
<tr>
<td>Disposal Readiness Review</td>
<td>2/1/17</td>
<td>7 days</td>
<td>This is KDP-F #2</td>
</tr>
<tr>
<td>Execute passivation activities</td>
<td>2/15/17</td>
<td>15 days</td>
<td>See end of mission plan for details.</td>
</tr>
<tr>
<td>Decommission Ground System Hardware (Excess) and Archive all documentation Code 500 (TWIKI) Facilities/Equipment Disposal</td>
<td>3/31/17</td>
<td>30 days</td>
<td></td>
</tr>
<tr>
<td>Contract/Agreement Modification and/or Closeout</td>
<td>4/1/17</td>
<td>30 days</td>
<td></td>
</tr>
<tr>
<td>EO-1 Operations and Science Documentation Closeout and Archive</td>
<td>4/1/17</td>
<td>180 days</td>
<td>Upload to Wiki and meet National Archive requirements with DVD’s</td>
</tr>
<tr>
<td>Spacecraft Final Report</td>
<td>6/30/17</td>
<td>75 days</td>
<td>Days from passivation completion</td>
</tr>
</tbody>
</table>
This figure shows the trending of the lunar calibration data over the mission duration. The plot shows that, except for the shortest wavelength in the VNIR focal plane (457.34), the Hyperion data are stable to within ± 1.5%. The data have been normalized to the first acquisition point, and are expressed as percent change from the beginning.
Some bands show signs of phase angle dependencies, e.g. 569, 660, 793, 864 and 1648 nm.

SUMMARY: The ROLO model provides a convenient avenue to conduct overall trending of instrument performance. But the ROLO model is unable to characterize individual detectors.
EO-1 ran out of orbital maintenance fuel in February 2011, when the Mean Local Time (MLT) was 10:00 AM. Since then it has been drifting lower in orbit and earlier in overpass time. EO-1 will reach 8:00 AM MLT by October 2016.

<table>
<thead>
<tr>
<th>Date</th>
<th>Predicted MLT (HH:MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/1/2016</td>
<td>08:25</td>
</tr>
<tr>
<td>5/13/2016</td>
<td>08:15</td>
</tr>
<tr>
<td>9/27/2016</td>
<td>08:00</td>
</tr>
<tr>
<td>1/26/2017</td>
<td>07:45</td>
</tr>
<tr>
<td>5/25/2017</td>
<td>07:30</td>
</tr>
<tr>
<td>9/14/2017</td>
<td>07:15</td>
</tr>
<tr>
<td>12/27/2017</td>
<td>07:00</td>
</tr>
</tbody>
</table>
Solar Zenith Angle at EO-1 Overpass

SZA depends on overpass time, latitude, and date. The larger SZAs occurring in 2016 have already been experienced by EO-1 in previous years (at higher latitudes and during winters).

Lines represent SZA at overpass time for different latitude bands.
For 40°N in 2016, approximately 60% of the time the SZA at EO-1 overpass time is within the previously experienced SZA range for that latitude.

Nominal 10:00 AM Overpass Time

2016
EO-1 Flight Systems

• Health and Safety of spacecraft (S/C) and subsystems continuing nominal operations

• Power Systems are working nominally
  – After performing a cycle of VT changes to help condition the battery for longer use (improves state of charge, speed of charge and differential voltage), the EO-1 VT is now set to a VT level of 4.5

• Instruments performing nominally
  – Solar and Lunar Calibrations routine including slow scan Hyperion and a negative phase angle lunar calibration to aid Landsat-8 in calibration

• No Life Limiting items identified that would prohibit passivation
EO-1 Mission Enhancements

• The EO-1 mission is out of usable fuel since February 2011 but attitude control system (ACS) fully functional
  – The spacecraft is no longer tasked to perform MLT maintenance burns (inclination burns).
• With a transition from MOPSS (old) to ASPEN (new) and CMS (old) to SCP (new) mission planning systems, the FOT couldn’t initially perform Delta-V maneuvers.
• The FOT created procedures and implemented a way to perform Delta-V maneuvers on the new mission planning systems to perform debris avoidance maneuvers.
EO-1 Mission Enhancements

• **EO-1 Lunar Calibration Modifications**
  – EO-1 FOT created a way to perform a single scan Hyperion centered lunar calibration
    • This calibration is performed prior to a positive phase nominal 4 scan lunar calibration with ALI and Hyperion
  – Removed all atmospheric corrector (AC) commands and reduced the nominal 5 scan positive phase lunar calibration to a nominal 4 scan positive phase lunar calibration (removed all AC scans/commands).
  – Conducted negative phase lunar calibrations in conjunction with Landsat-8
EO-1 Debris Avoidance Maneuver

• The EO-1 spacecraft had a close approach with a (FENGYUN 1C DEB) on 5/10/2014 at 17:57:40 GMT
  – Miss distance of ~167m
• The EO-1 FOT team worked with ESMO and CARA to plan and perform a 10 second Delta-V maneuver on 9 May 2014 at 13:30 GMT.
  – The Burn was successful, the spacecraft thrusters fired for the full 10 seconds.
EO-1 Recent Anomalies

• All Anomaly Reports available at https://eo1.gsfc.nasa.gov/
EO-1 Orbital Information

- EO-1 Orbit Information on 03/13/15 00:00:00z
  - Semi-major Axis = 7065.655 Km
  - Eccentricity = 0.000545
  - Inclination = 97.936 Deg
  - RAAN = 338.705 Deg
  - Argument of Perigee = 50.504 Deg
  - True Anomaly = 137.525 Deg
  - Altitude at Apogee = 691.366 Km
  - Altitude at Perigee = 683.669 Km
Earth Observing-1 Inclination Status for the MOWG

FreeFlyer Plot

03/13/2015

[Graph showing the inclination status over time]
ALI data taken at an 8 AM equatorial crossing time is valuable in spite of the decline in SNR

• The ALI SNR is inherently 6 to 10X (~800%) that of ETM+.
• The ALI signal at 8 AM always exceeds 50% of the 10 AM.
• ALI SNR at 8 AM will be 3 to 5X better than that of ETM+ at 10 AM.
• EO-1 will not reach an 8 AM crossing time until October 2016.

Signal (i.e. solar irradiance) is a function of the cosine of the solar zenith angle (SZA).
EO-1 Orbit Plots 5 Year Outlook
Semi-Major Axis Altitude
(0.00 Feb 2016)
EO-1 Orbit Plots 5 Year Outlook
Apogee and Perigee Altitude
(0.00 = 1 Feb 2016)
EO-1 Altitude as a Function of Latitude
(for the first orbit on January 4, 2015)

- 705 km "Circular" Orbit
- EO-1 Descending Orbit
- EO-1 Ascending Orbit

Altitude as a Function of Latitude

- Descending (Day-time) N to S
- Ascending (Night-time) S to N
Future NASA Budget Outlook

• Full year of operations during FY2016 with decommissioning starting October 2016 has been authorized

• Phase F report for decommissioning management starting October 2016 submitted to NASA Headquarters 31 March 2016
Backup
EO-1 New Ground Stations

– EO-1 Flight Operations Team (FOT), Earth Observing Systems (EOS) Data and Operations System (EDOS), Near Earth Networks Services (NENS), Universal Space Network (USN), and Wallops and White Sands scheduling personnel worked to switch from PF1/PF2 to Northern Alaska ground stations

  • testing of S-band uplink/downlink, X-band downlink, and telemetry tracking for new ground stations in northern Alaska designated USAK-02/03/04
  • coordination of firewall rule updates
  • conducting test passes over the new ground stations
  • implementation of modifications to the ground and flight software to point the satellite antenna at the correct locations
  • analysis of the command link, telemetry receipt, science data capture, and ranging/tracking data files for operational readiness
The alternative way to understand and assess the stability of Hyperion is to perform a SBAF time series study.

- Figure shows the SBAF (OLI/S2) stability is better than 0.1% for last 12 years (except for blue band).
- This would also mean that constraint on simultaneous image pair based cross calibration can be relaxed to take advantage of the long term stability of the site,
- The stability of Landsat 8 and Sentinel-2 reduces the impact of an eventual loss of Hyperion.

Helder, et al. 2015