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

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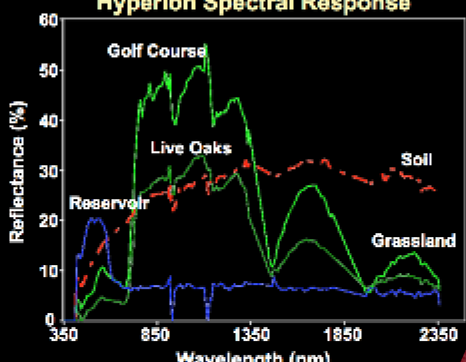
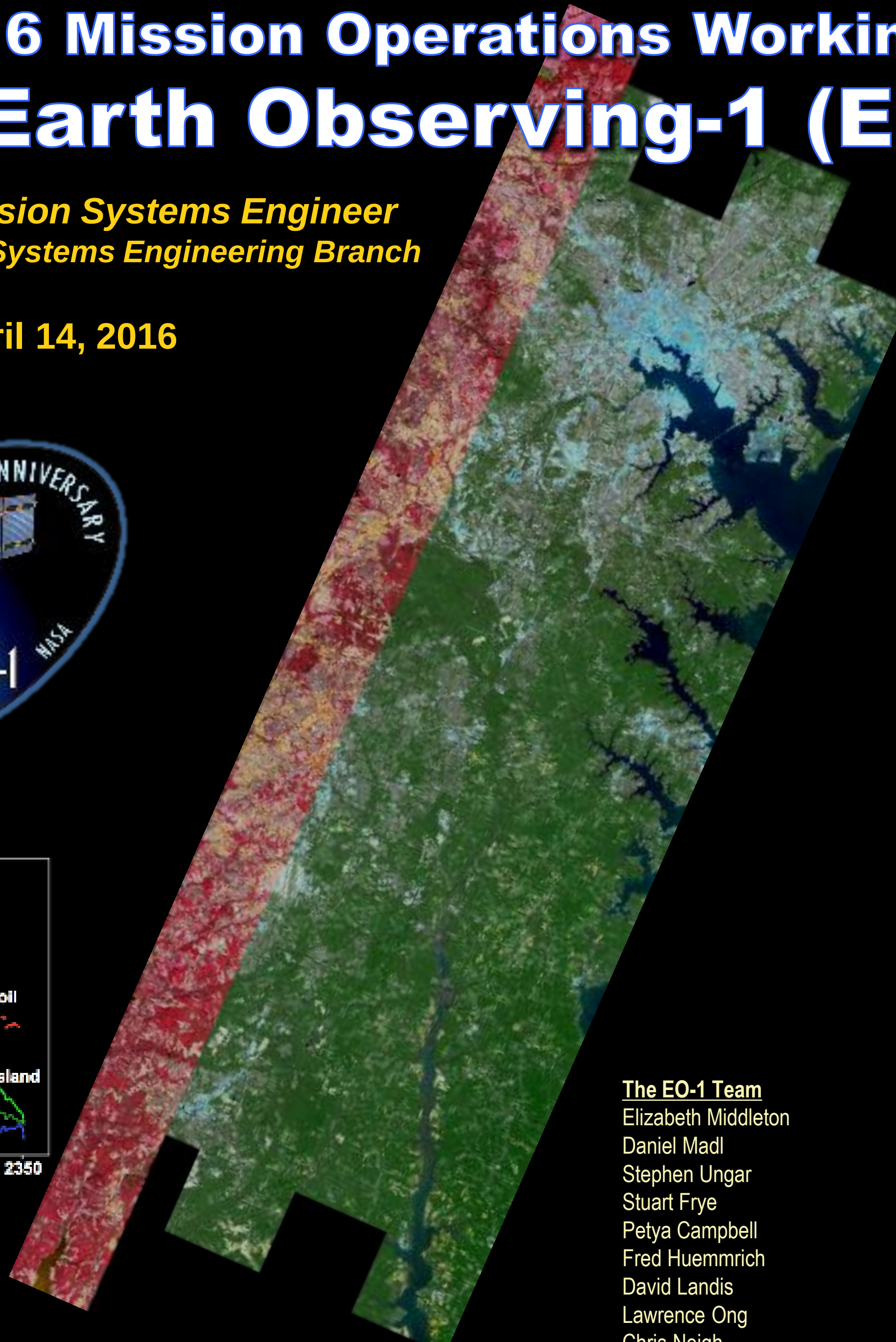
Code 581 Software Systems Engineering Branch

April 14, 2016

Hyperion Spectral Response





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

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

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David Landis
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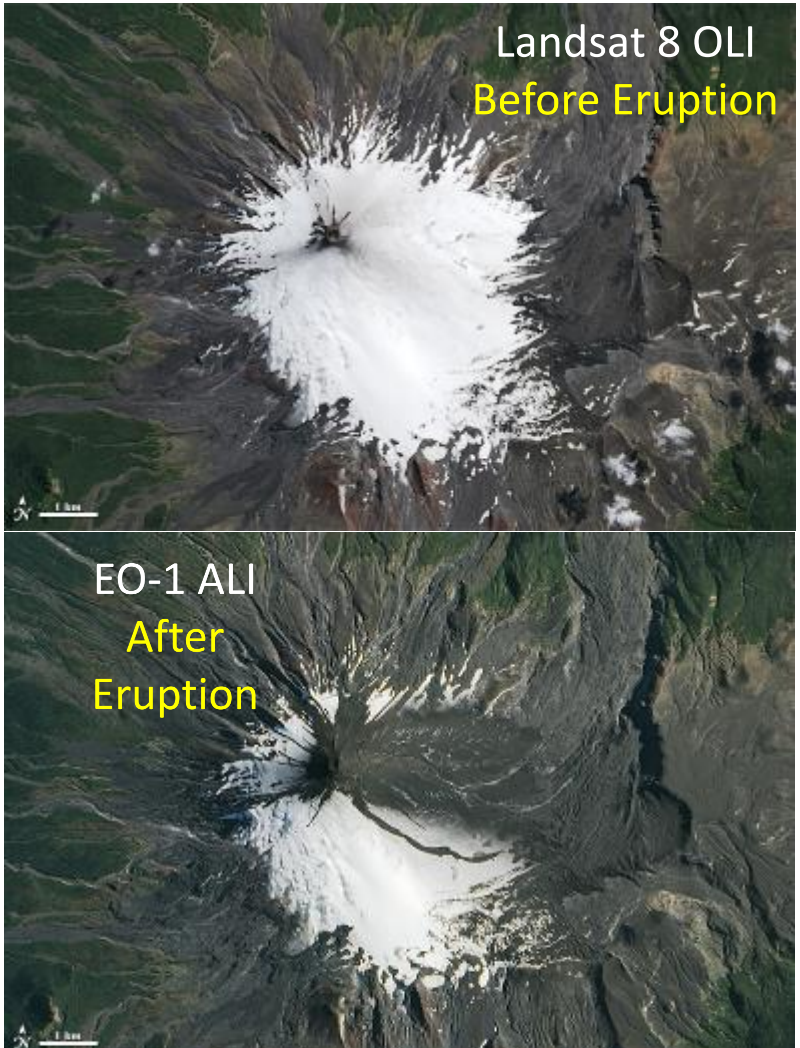
Chris Neigh

EO-1 Complimenting Landsat 8 and MODIS



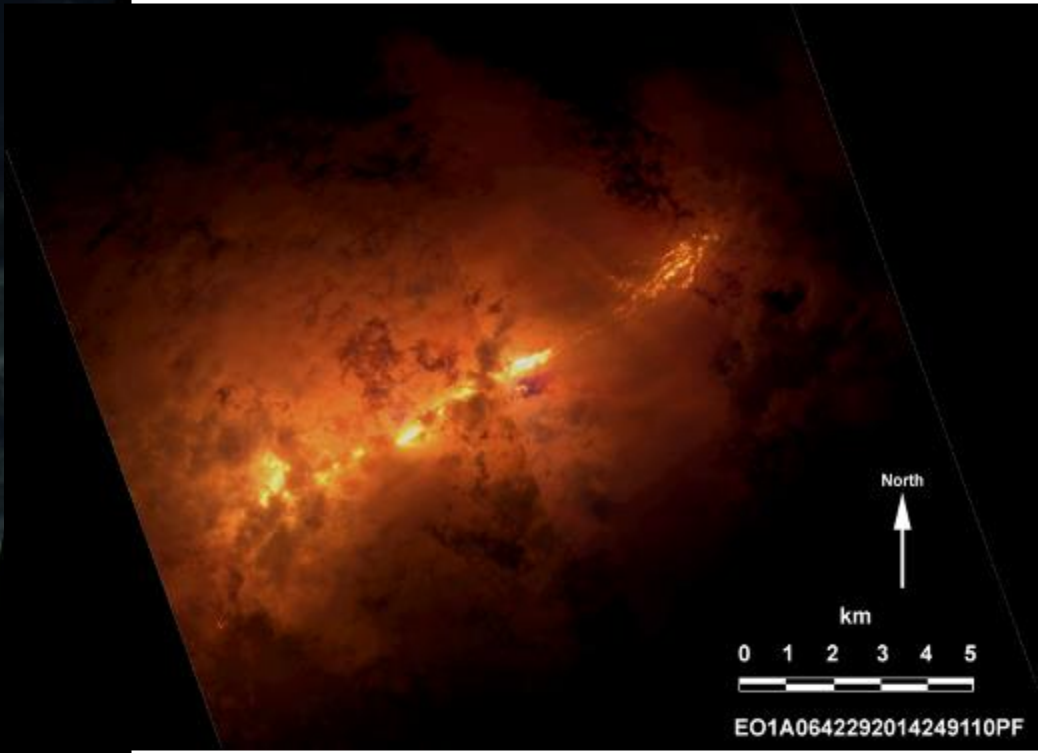
EO-1 ALI complementing OLI. When the Villarrica Volcano erupted, EO-1 was able to acquire an image on March 5, 2015 – **five days before** the next Landsat 8 overpass.

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

EARTH OBSERVATORY
Where every day is Earth Day

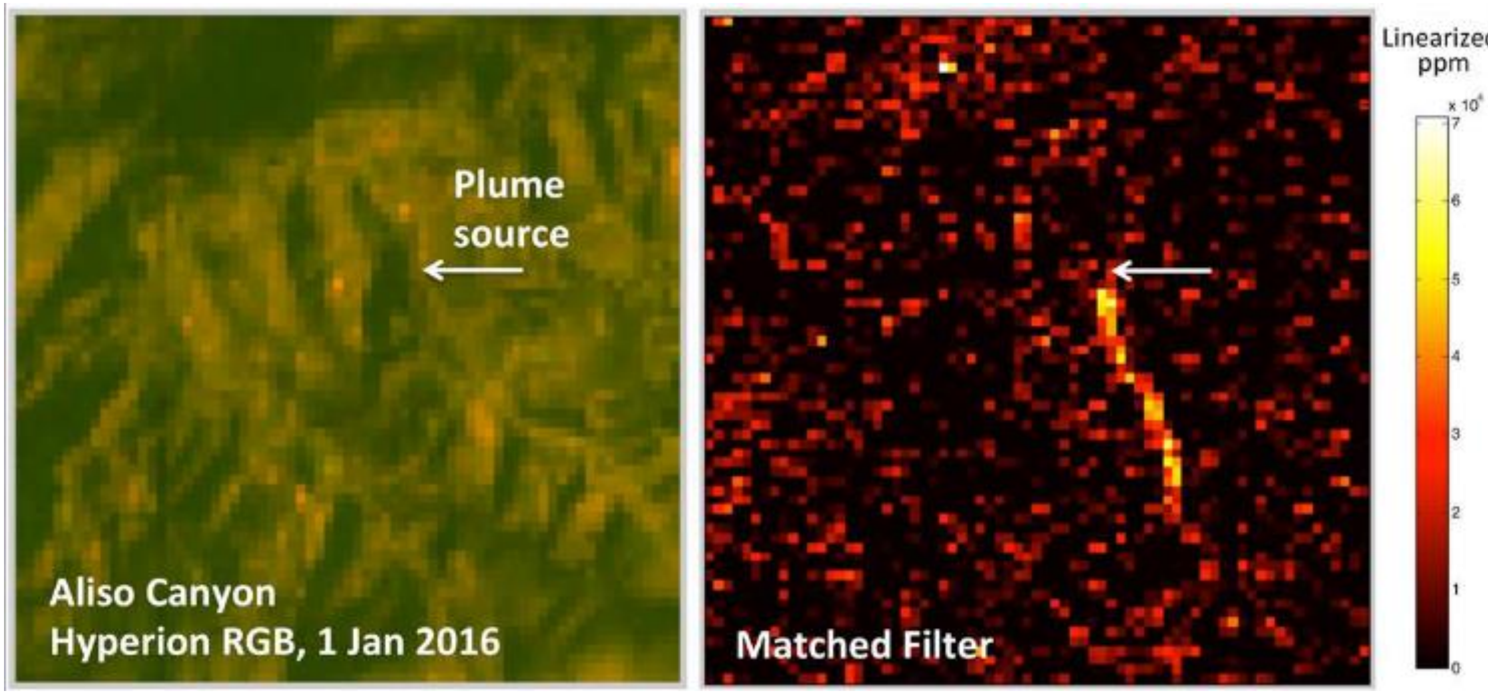
EO-1 Image Gallery

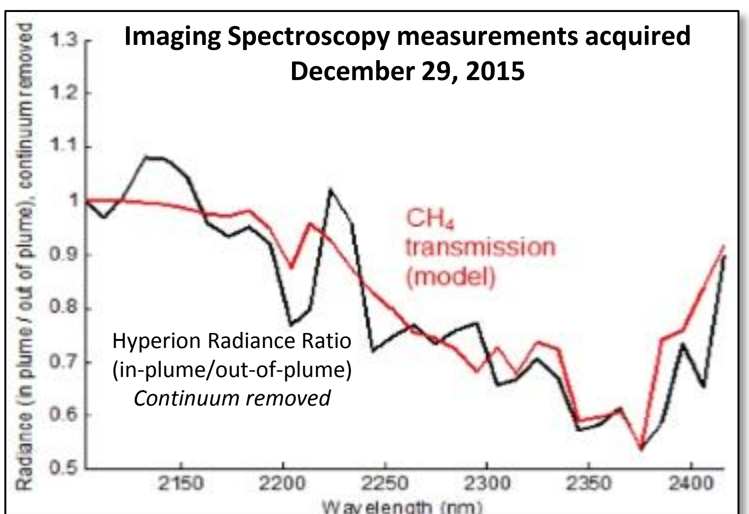
EO-1 image of Wolf Volcano in Galapagos
Eruption on May 25th, image acquired on May 28th



EO-1 ALI night-time image of Holuhraun Iceland volcano

Hyperion Detects the California Methane Leak



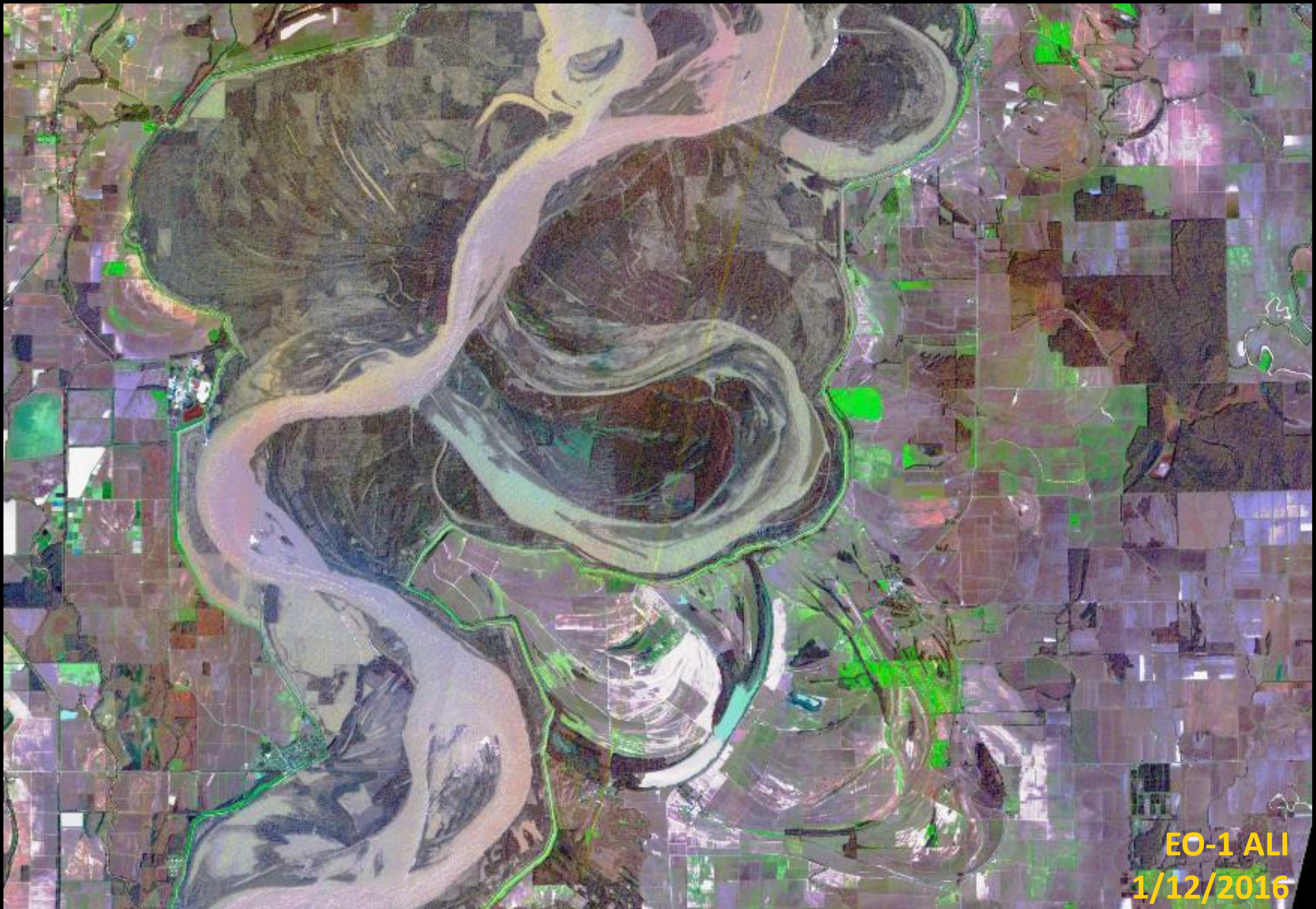


On January 1, 2016, Hyperion imaged the massive methane leak in the Aliso Canyon region of California. David Thompson's (JPL) algorithm detected the methane leak within the Hyperion data and showed a pronounced plume trending to the south. Since then, six additional acquisitions have been made, thanks to EO-1's ability to rapidly schedule, reorient satellite attitude, and quickly process and distribute the data.

Hyperion Matched Filter Detection Technique Provided by
D. Thompson, A. Thorpe, R.O. Green and The Imaging Spectroscopy Team, JPL, CalTech

2016 Flooding on the Mississippi River

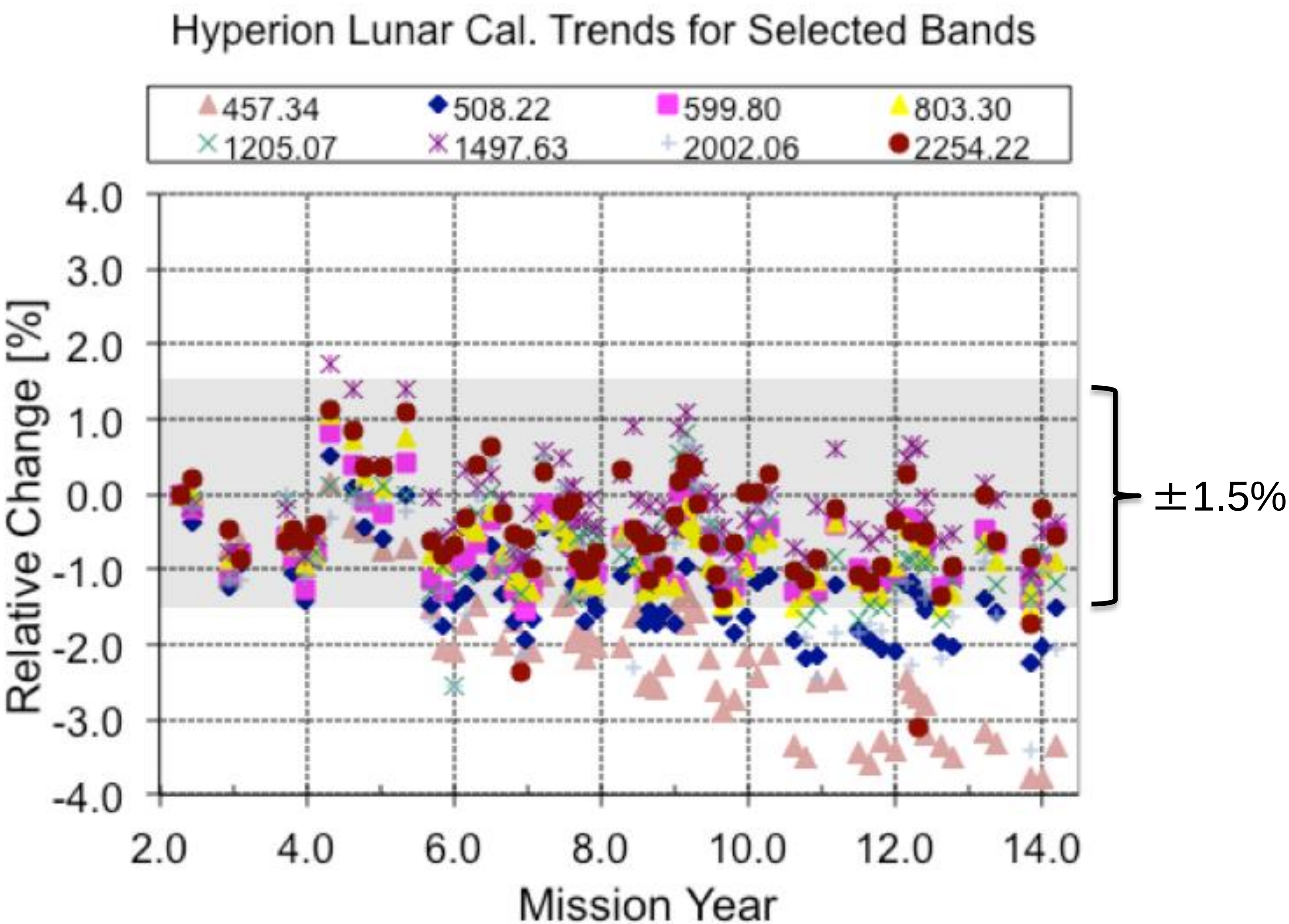
2016 Flooding on the Mississippi River



EO-1 Phase F Decommissioning Timeline

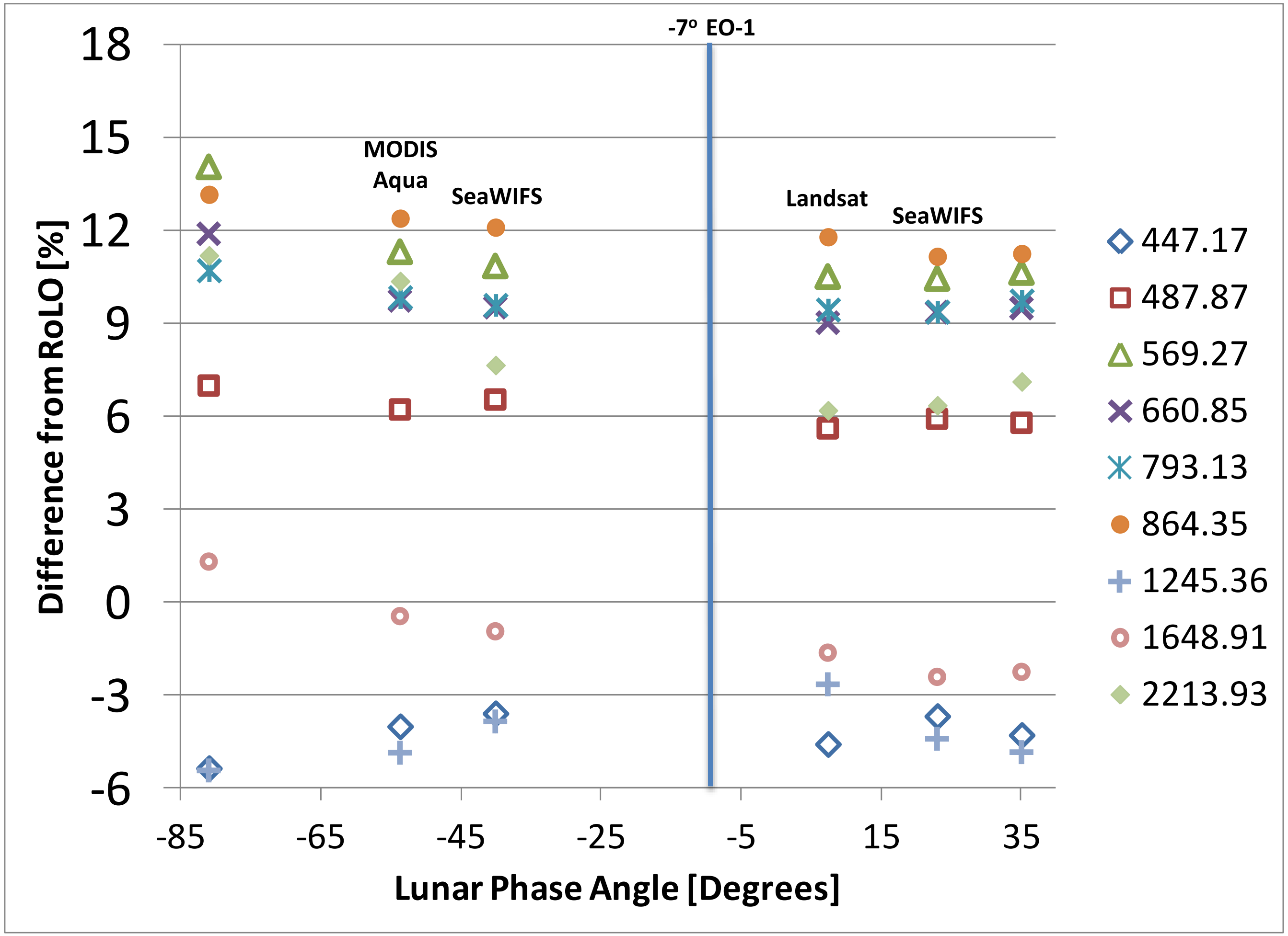
Mission Operations, Science and Decommissioning Timeline	Beginning Date of Activity	Duration	Comments
Science Activities			**Selected Key Activities**
Generate Level 2 Reflectance	10/1/16	1 year	Provided on demand, improvements for water and diverse terrain
Prototype Land Cover Products			For HyspIRI,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

Hyperion Lunar Trends



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.

Comparisons with ROLO at Various Phase Angles

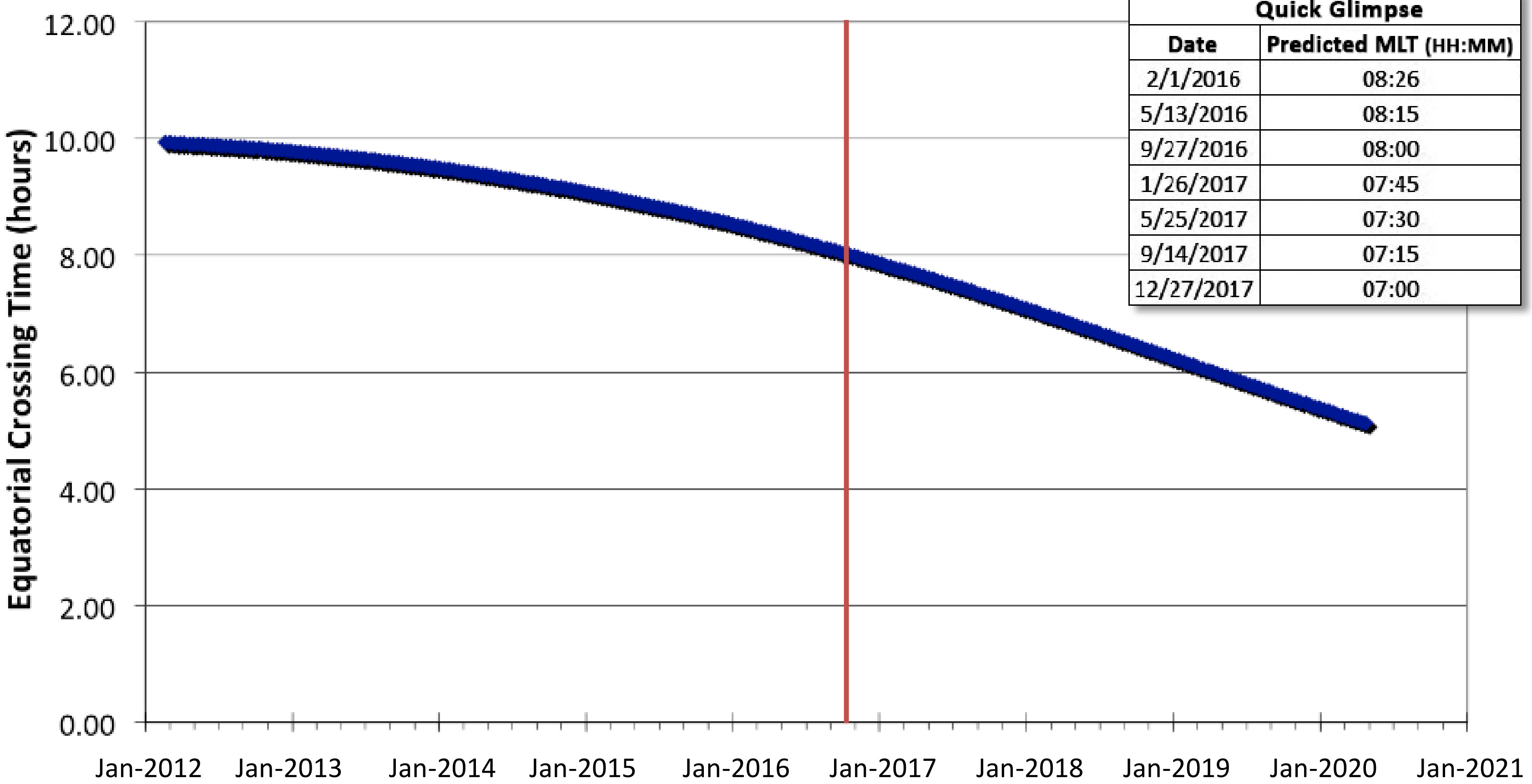


Some bands show signs of phase angle dependencies, e.g. 569, 660, 793, 864 and 1648 nm.

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.

Change in EO-1 Equatorial Crossing Time

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.

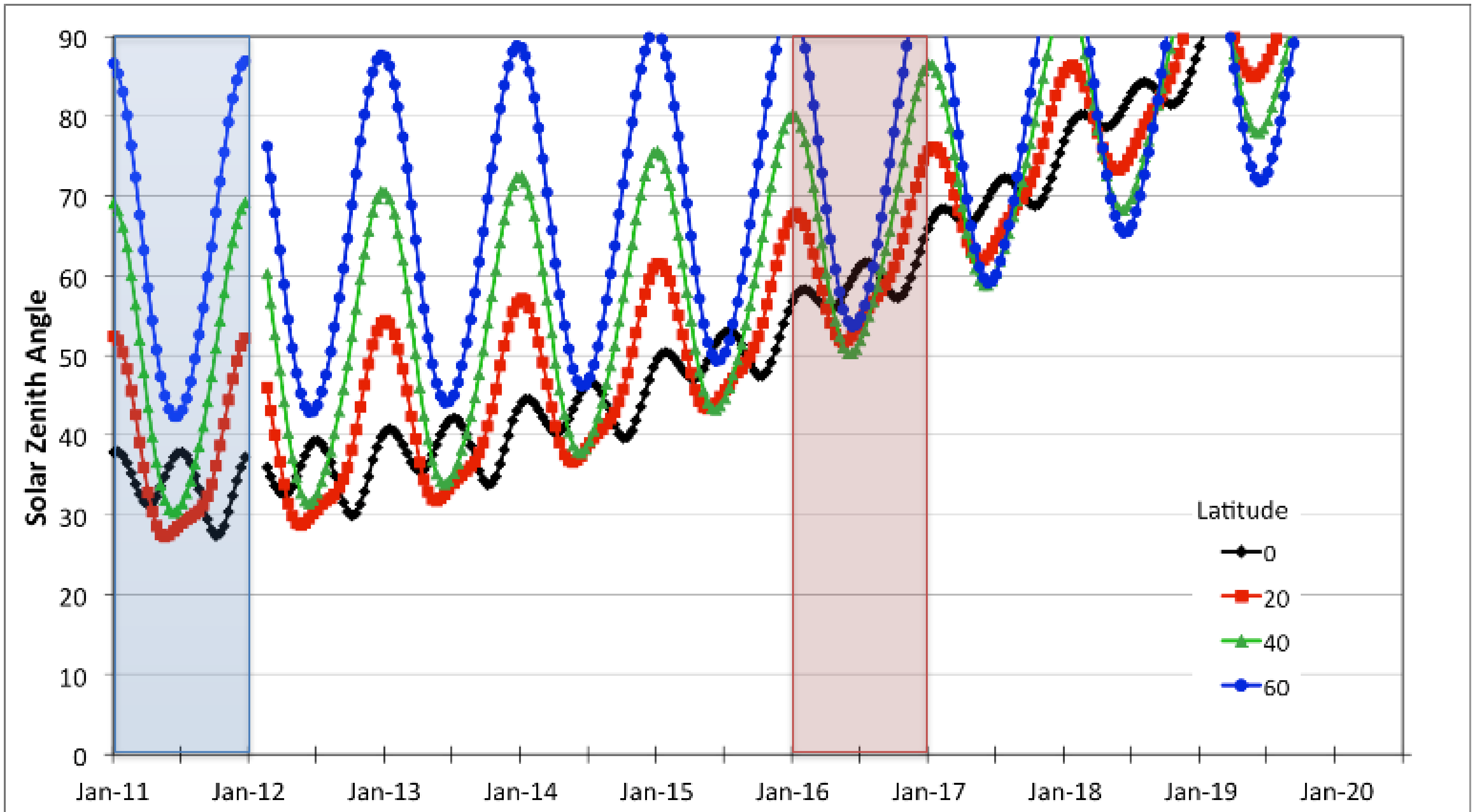


Quick Glimpse

Date	Predicted MLT (HH:MM)
2/1/2016	08:26
5/13/2016	08:15
9/27/2016	08:00
1/26/2017	07:45
5/25/2017	07:30
9/14/2017	07:15
12/27/2017	07:00

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).



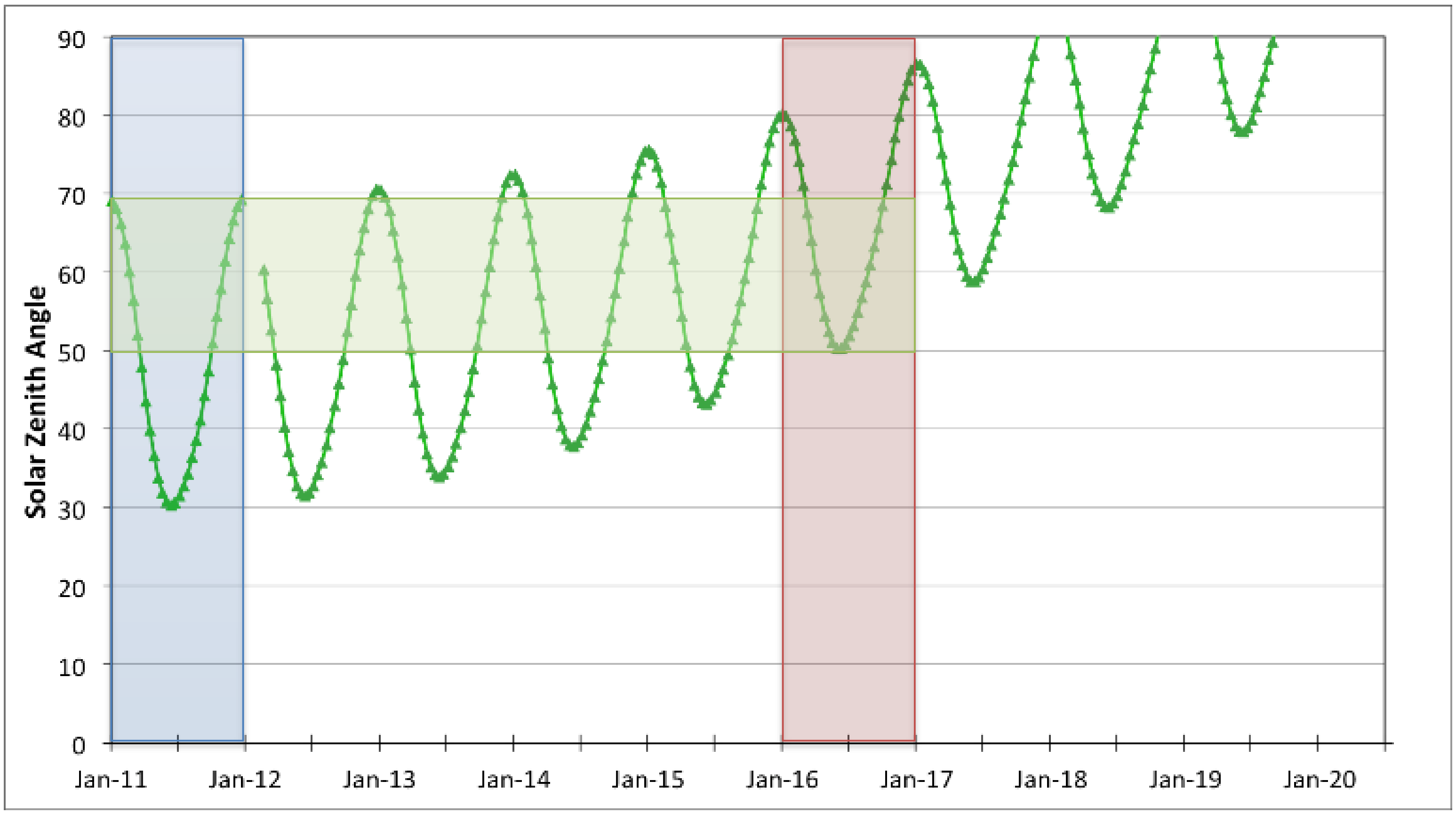
Nominal 10:00 AM Overpass Time

2016

Lines represent SZA at overpass time for different latitude bands

Solar Zenith Angle at EO-1 Overpass 40°N

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.

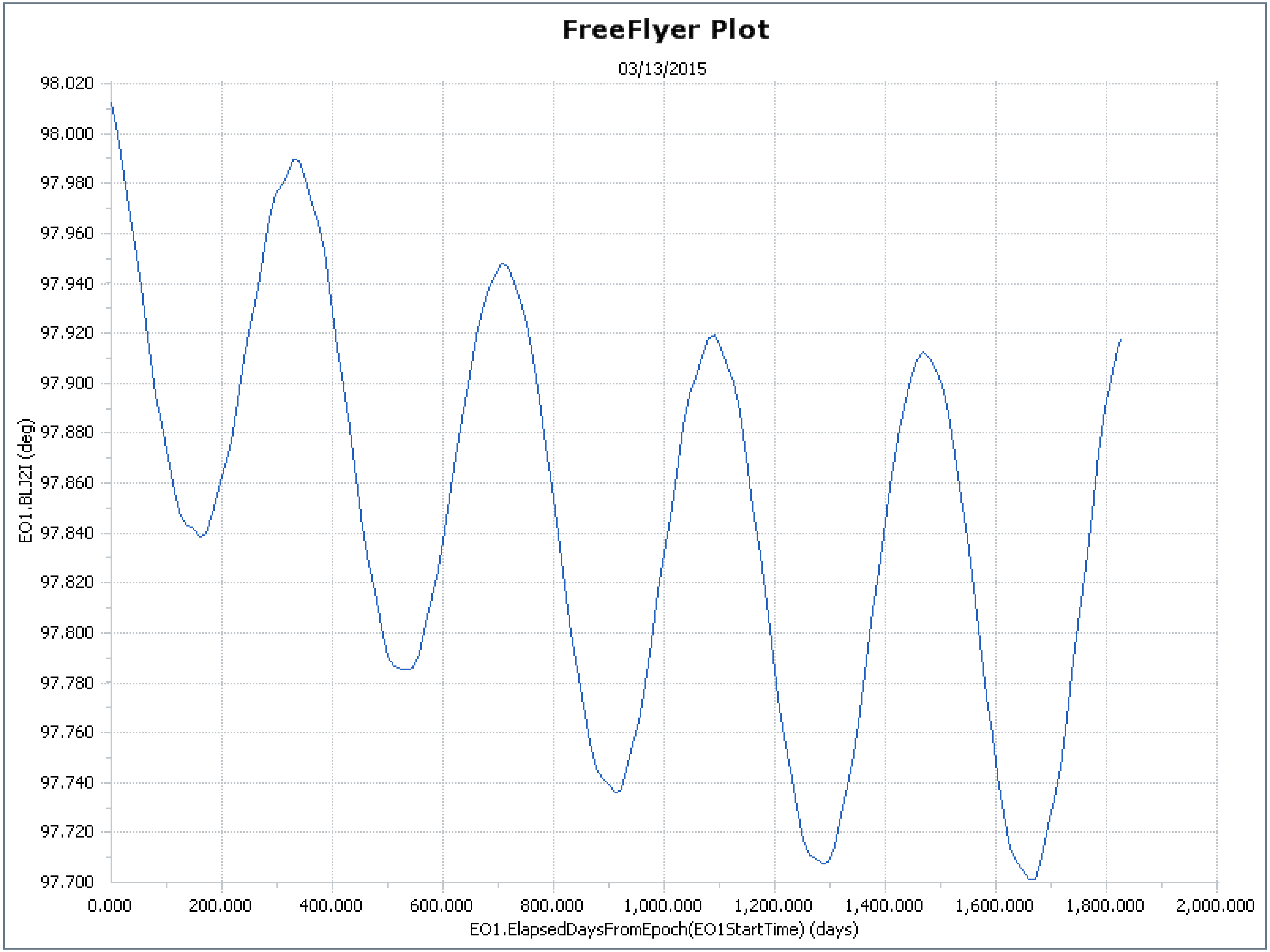
EO-1 Recent Anomalies

- **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



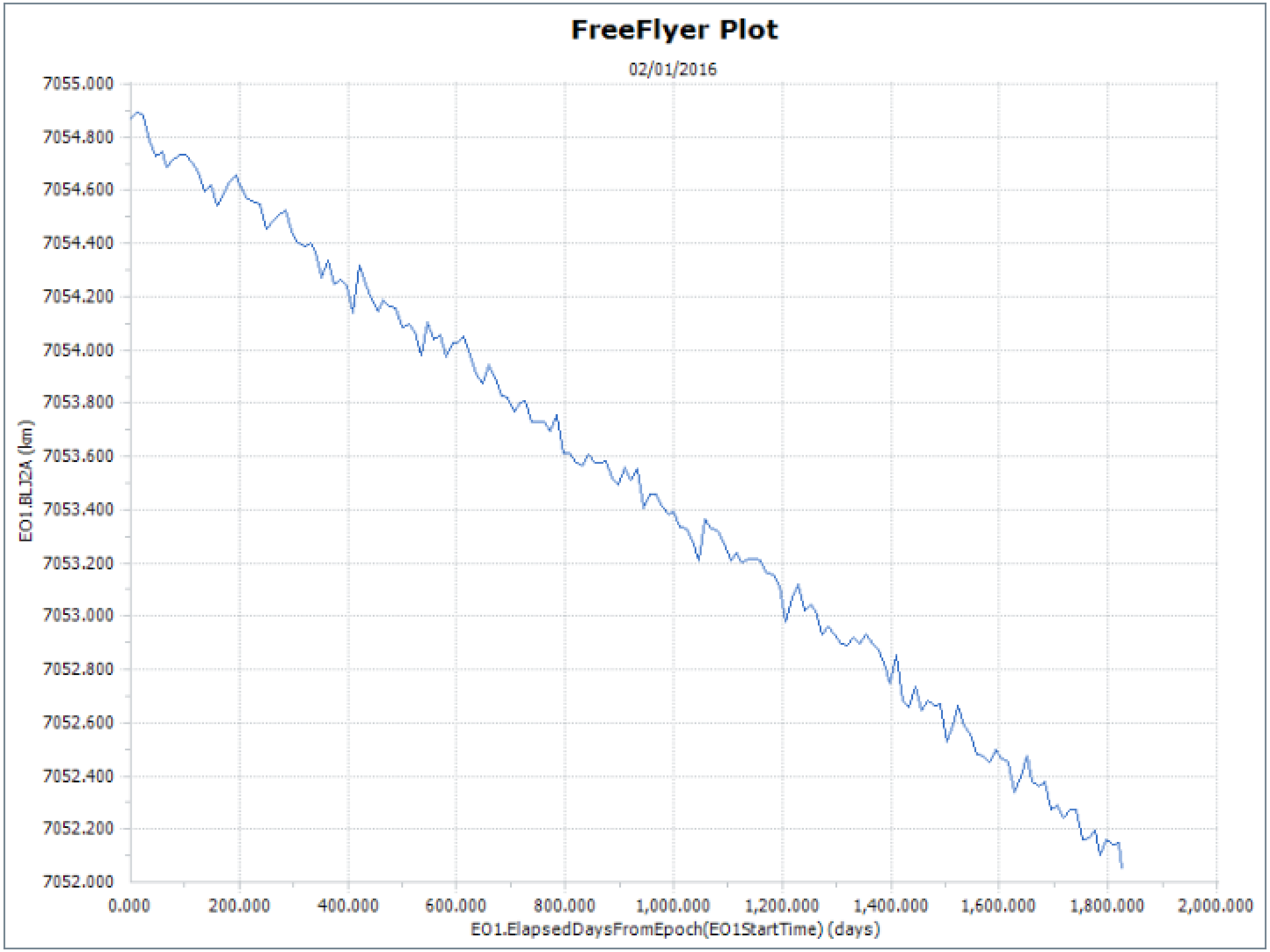
ALI data taken at an 8 AM equatorial crossing time is valuable in spite of the decline in SNR

- 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.

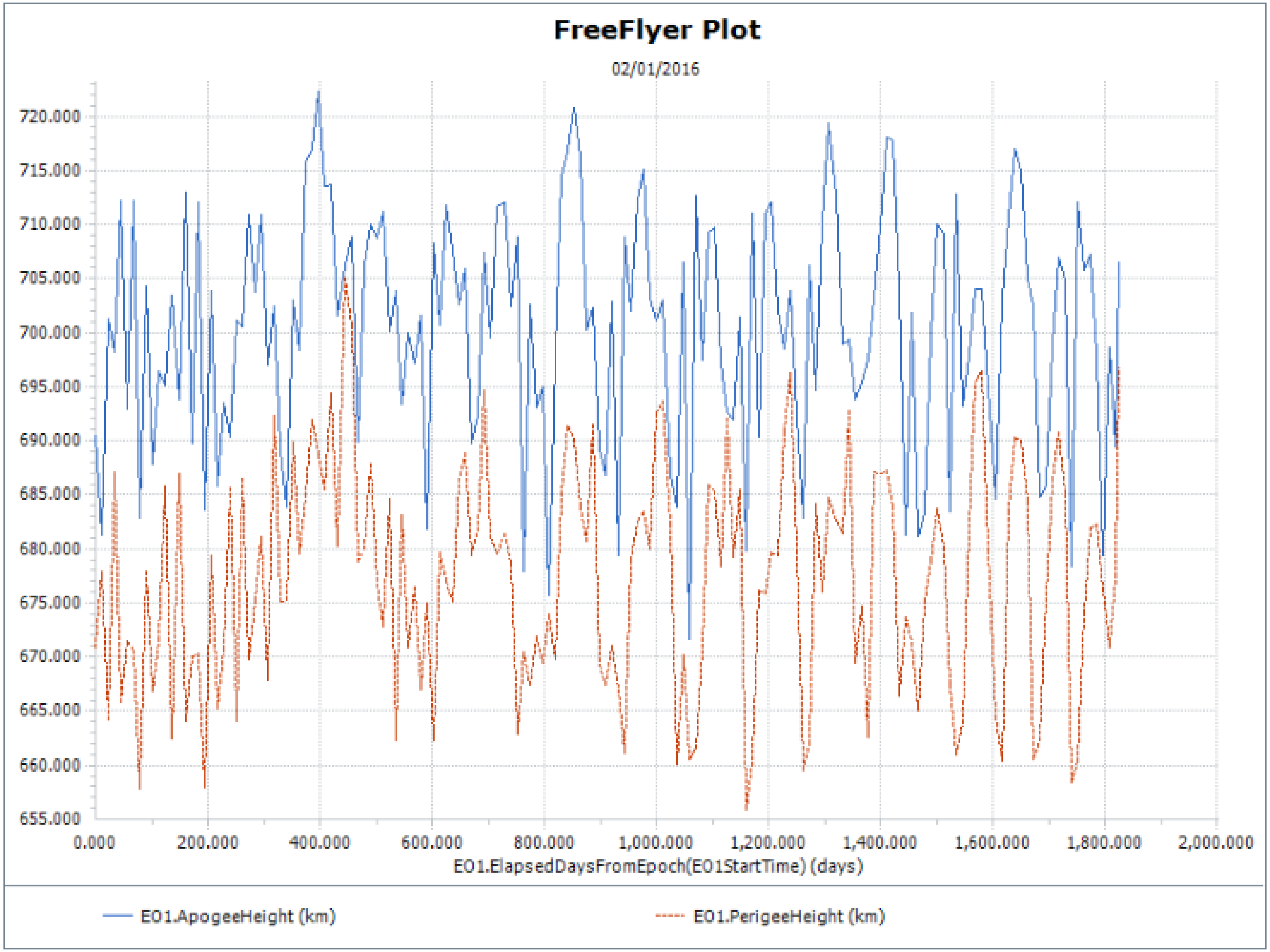
Crossing Time at Equator	March 22		June 22		September 22		December 22	
	Elevation (degrees)	cos(SZA)	Elevation (degrees)	cos(SZA)	Elevation (degrees)	cos(SZA)	Elevation (degrees)	cos(SZA)
8:00 AM	28.3	0.47	26.9	0.45	31.8	0.53	27.7	0.46
8:30 AM	35.8	0.58	33.5	0.55	39.3	0.63	34.3	0.56
9:00 AM	43.8	0.69	40.1	0.64	54.3	0.81	40.8	0.65
9:30 AM	50.8	0.77	46.3	0.72	46.8	0.73	47.0	0.73
10:00 AM	58.3	0.85	52.3	0.79	61.8	0.88	52.9	0.80
12:00 PM	88.14	1.00	66.57	0.92	88.17	1.00	66.57	0.92
Signal@8 AM / Signal@10 AM		**0.56**		**0.57**		**0.60**		**0.58**

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)

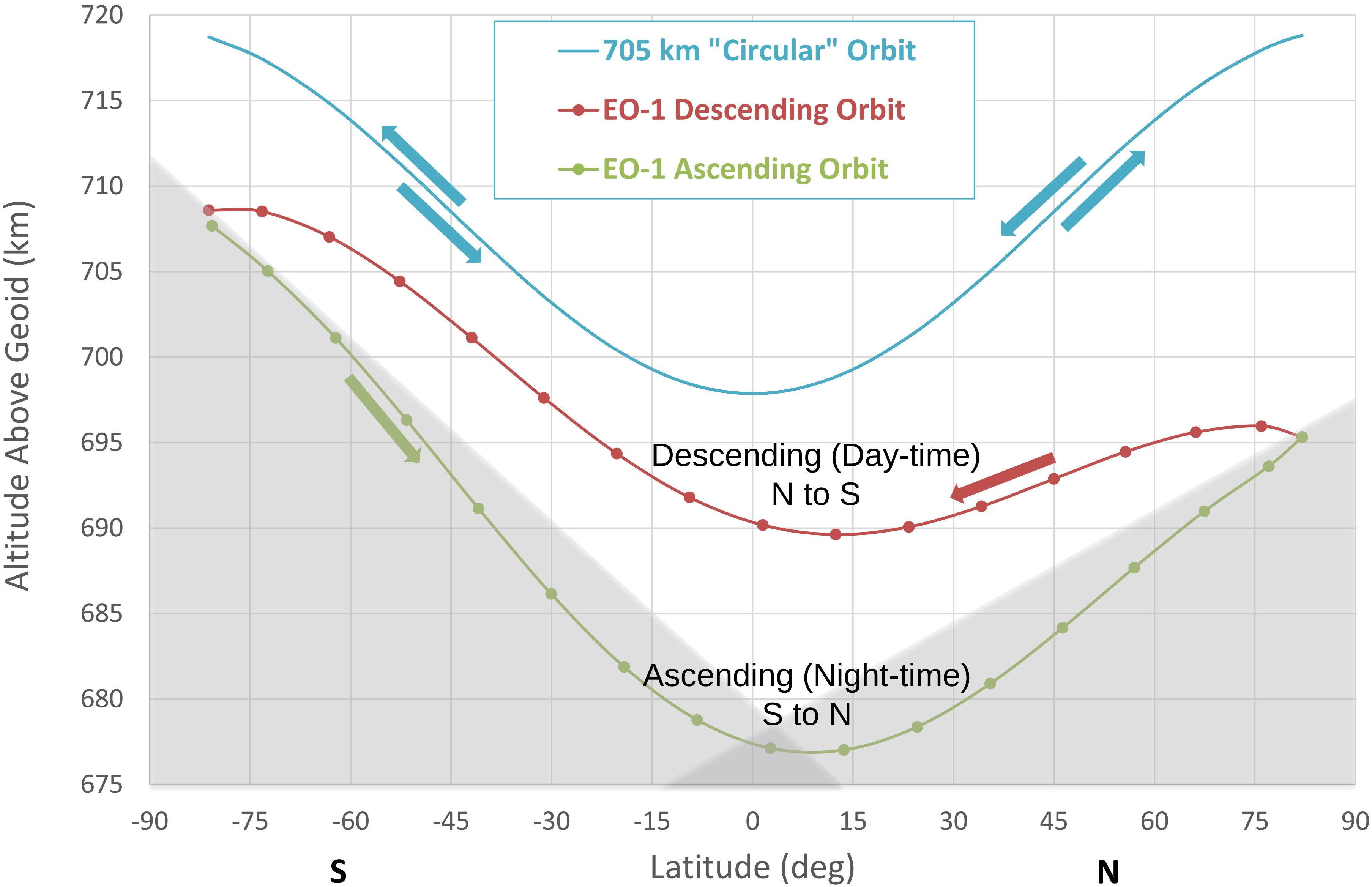


EO-1 Orbit Plots 5 Year Outlook
Apogee and Perigee Altitude
(0.00 = 1 Feb 2016)



EO-1 Altitude as a Function of Latitude

(for the first orbit on January 4, 2015)



Future NASA Budget Outlook

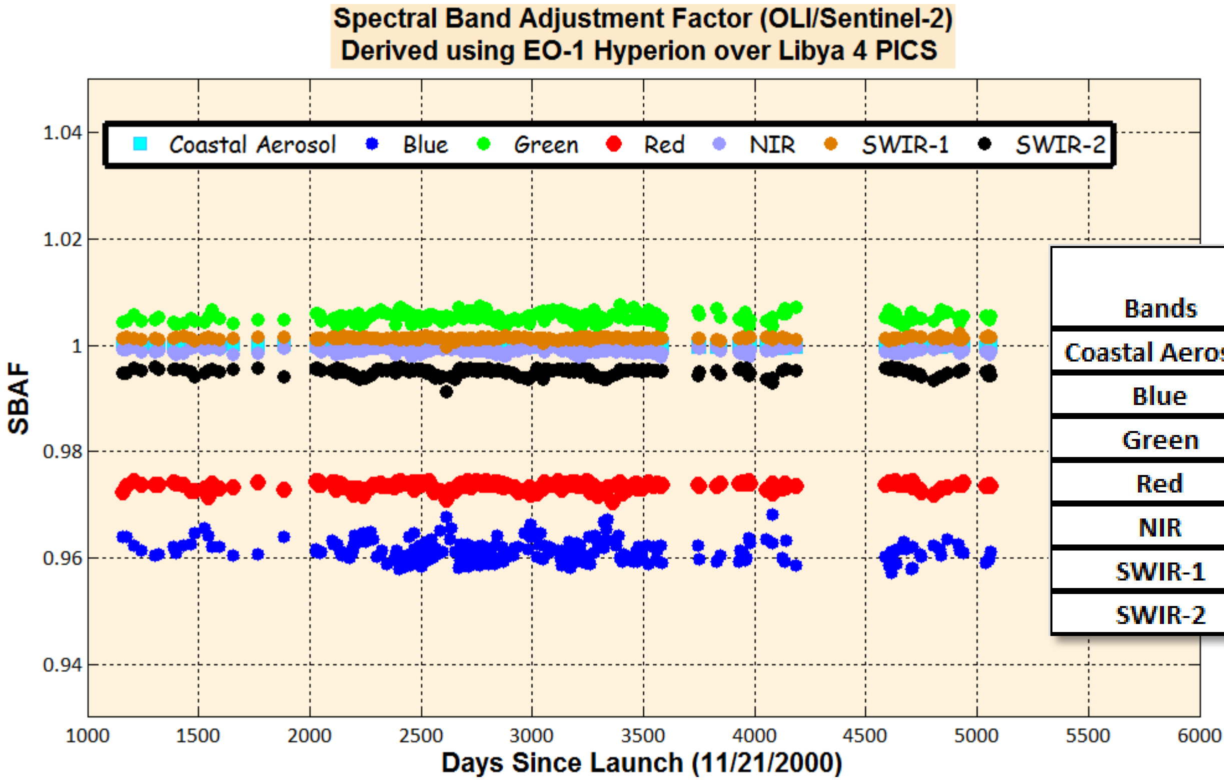
- Full year of operations during FY2016 with decommissioning starting October 2016 has been authorized
- Phase F report for decommissioning management starting October 2016 submitted to NASA Headquarters 31 March 2016

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 Long Term Stability of Hyperion



Bands	Avg. SBAF	Uncertainty (Stdev/ Mean)%
Coastal Aerosol	1.000	0.02%
Blue	0.961	0.21%
Green	1.005	0.08%
Red	0.974	0.07%
NIR	0.999	0.05%
SWIR-1	1.001	0.02%
SWIR-2	0.995	0.07%

- 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