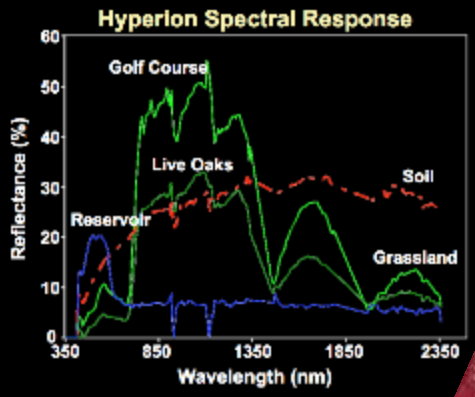
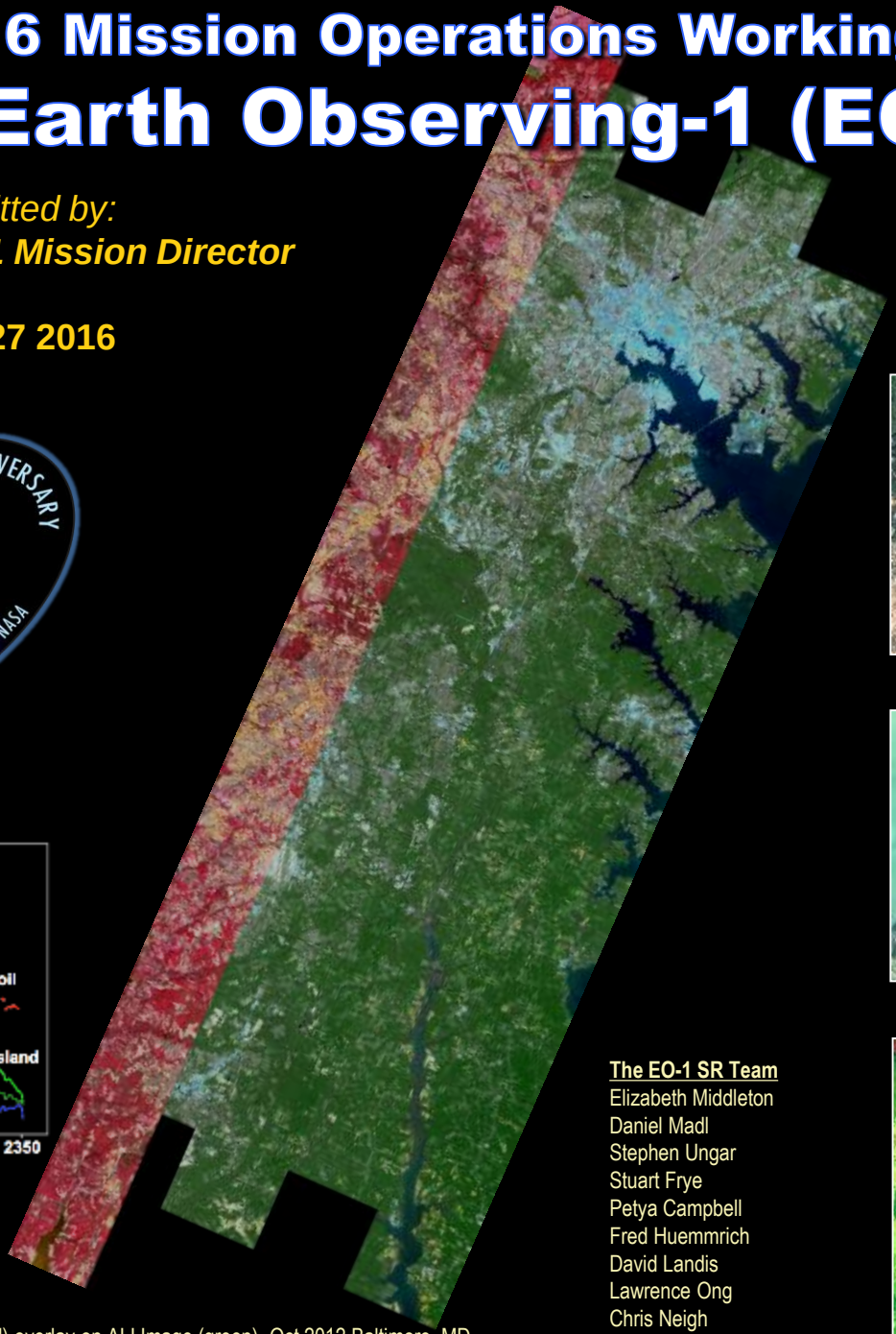
# 2016 Mission Operations Working Group

# Earth Observing-1 (EO-1)

*Submitted by:*
***Dan Mandl, EO-1 Mission Director***

**Sept 27 2016**

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

**The EO-1 SR Team**
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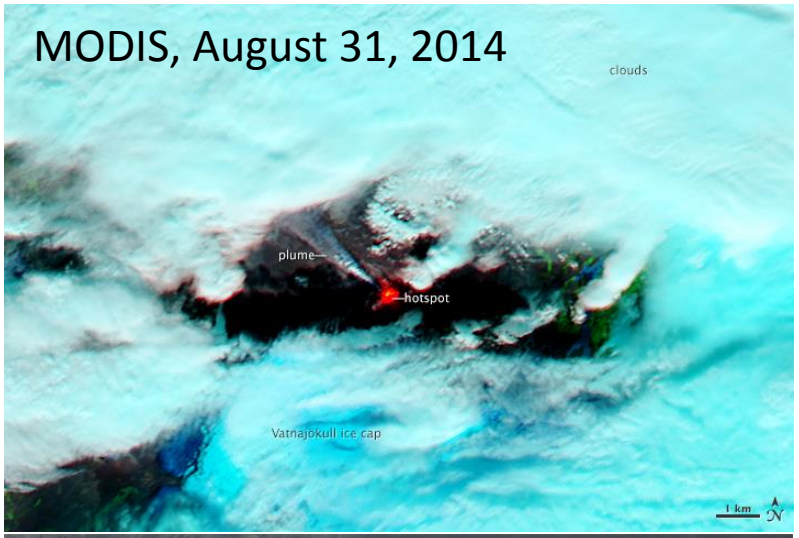
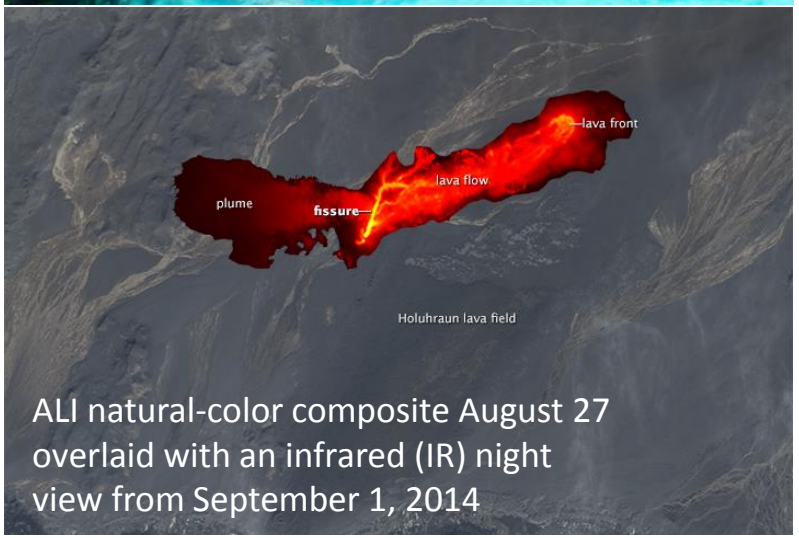
# EO-1 Complimenting Landsat 8 and MODIS



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.

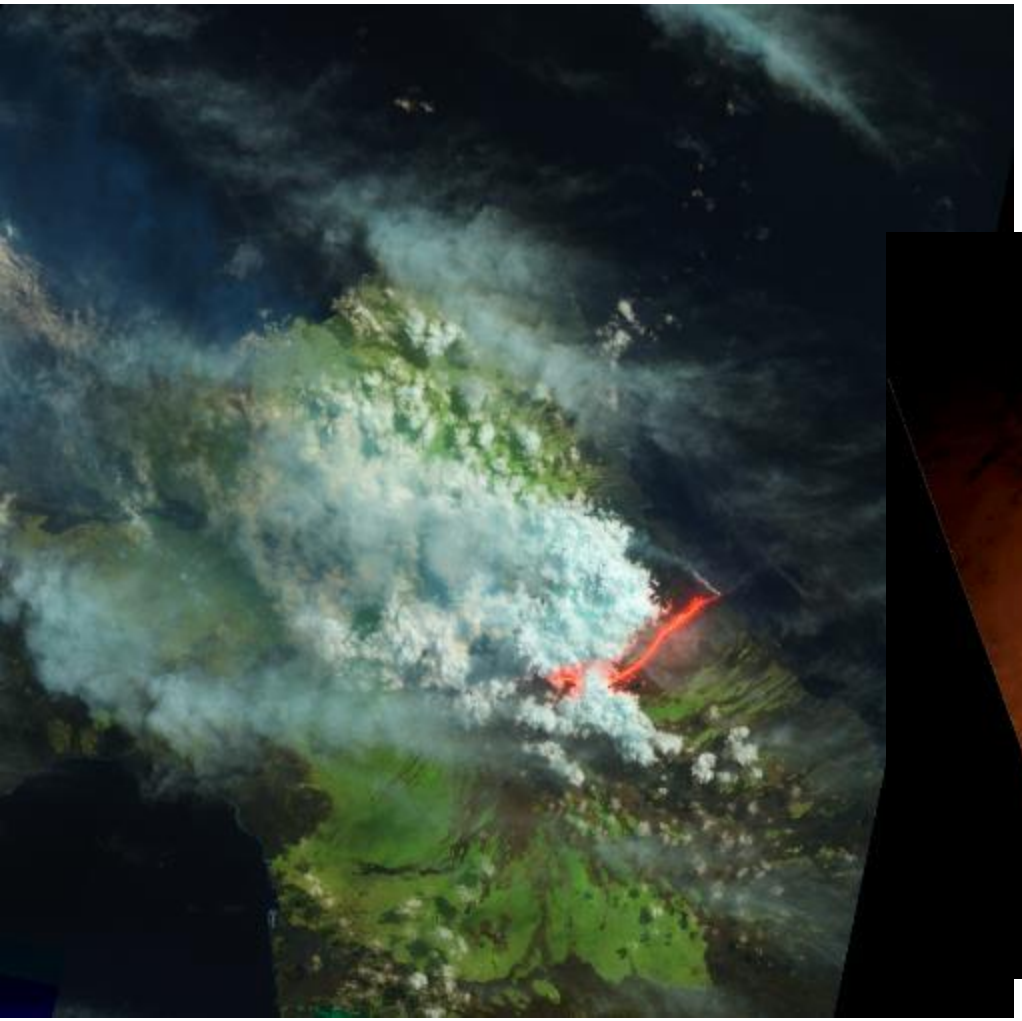


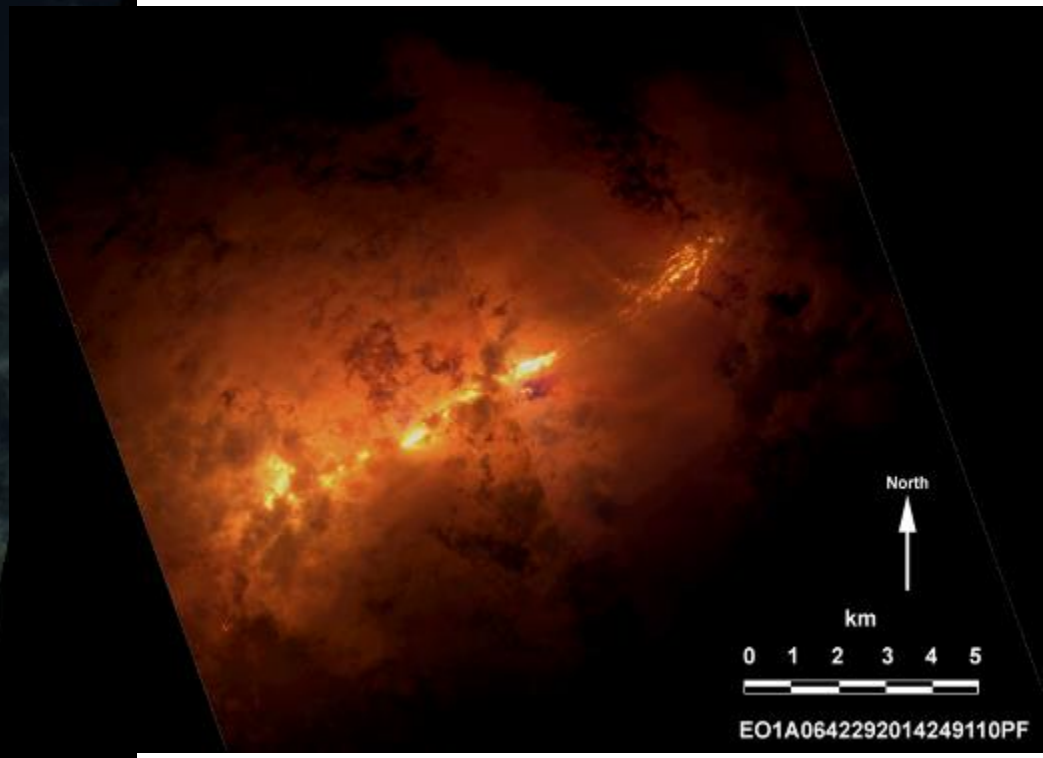

EO-1 ALI night-time image of the Vatnajokull volcano complementing MODIS (top).

EARTH OBSERVATORY
Where every day is Earth Day

# EO-1 Image Gallery

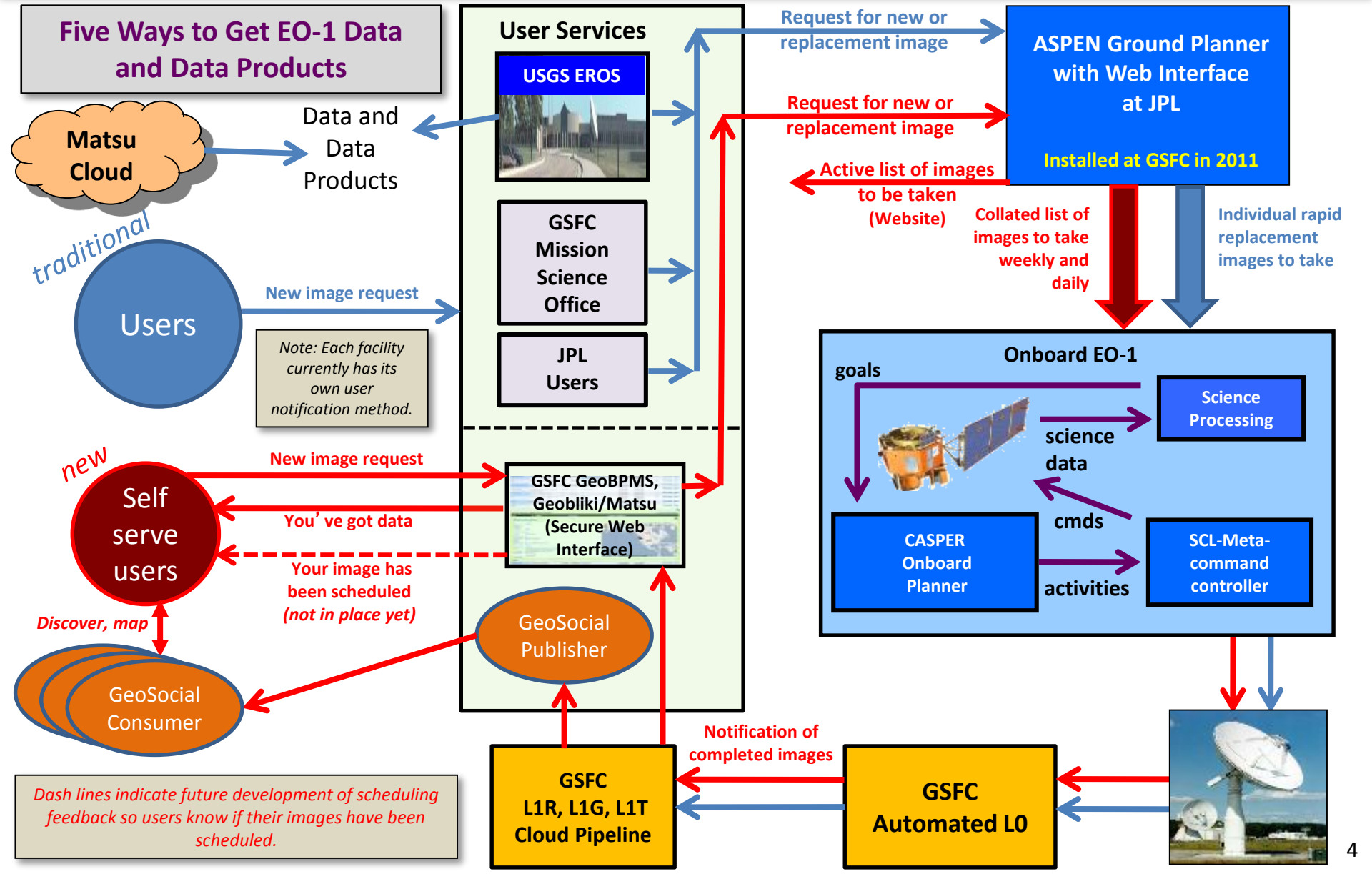


EO-1 image of Wolf Volcano in Galapagos
Eruption on May 25th, image acquired on May 28th




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

# EO-1 Image Tasking and Data Product Architecture



# Identification of EO-1 Life Limiting Components

| | Item | Vendor | Model | Comment |
|---|---|---|---|---|
| √ | 1. Battery | Boeing (Hughes) | GFE | 22-cell, 50-Ah, 28-V Super NiCad. Oversize TRMM spare. TRMM has been in orbit seventeen years with no catastrophic failures. Trend data continues to show nominal voltage/current/temperatures for EO-1. GSFC Code 563 performing ongoing trend monitoring. Based on TRMM heritage, mission engineering believes it is highly probable that the life will extend to at least 10/2017. Only Battery changes that were observed were differential voltage changes. This is caused by one side of battery charging faster than the other. Recovery was to slow the charge rate to reduce differential amount and eliminate night-time slews later than 33 minutes into eclipse. Impact: Conditioned battery so that the differential charge rate disappeared by May 2012. Charge rate returned to launch setting and remains there as of April 2015. |
| √ | 2. Solar Array Drive/ Cable Wrap | MOOG (Schaffer) | GFE | TRMM component. Has exceeded 11M deg travel qualification test limit. Disassembly after test showed no wear. Internal temperatures of approx. 25° C well within bearing oil operating range of 0-45° C. Drive motor operation trend data indicates no loss of step counts as of April 2015. |
| √ | 3. Solar Array Cells | EMCORE (TecStar) | 15% BSFR Si | By-pass diode protection for 31-cell sub-strings on outboard panel. Trend data shows nominal performance. GSFC solar cell expert expects no life limiting issue for cells. Output trending shows no degradation in performance as of April 2015. |
| √ | 4. Solar Array Cells | EMCORE (TecStar) | 22% DJ GaAs | Inherent solar cell by-pass diode protection. Wired as “fixed” segment. Trend data shows nominal performance. GSFC solar cell expert expects no life limiting issue for cells and no life limiting issues have been identified as of April 2015. |
| √ | 5. Solar Array Wiring | EMCORE SWALES | | Cell interconnects triple redundant and all array wiring is dual redundant. No issues exist for wiring as of April 2015. |
| √ | 6. Reaction Wheels | Ithaco/ Goodrich | Type A w/MDE | Three wheels with on-axis orthogonal mounting. All three wheels needed to perform science. Ithaco Life Expectancy Report dated 05/2000 gives rated life >15 yr. Bearing wear is considered the critical lifetime issue and is controlled by bearing lubrication. A life-test for bearing/lubricant EO-1 design was started April 1995 and is still running. Temperature trends show no sign of variance from launch through April 2015. |
| √ | 7. Star Tracker | Lockheed Martin | AST-201 W/1773 | Has shown susceptibility in the South Atlantic Anomaly but with auto recovery from SEU. Background noise trend data well within limits. With box shielding judged to be at least 100 mils total and least tolerant parts rated at 17 krad, Star Tracker performance nominal as of April 2015. (1) (Note that optical front end provides less shielding for roughly 12% of the surface area.) |

√ - Fully assessed and considered not to be life limiting.

# Identification of EO-1 Life Limiting Components

| | Item | Vendor | Model | Comment |
|---|---|---|---|---|
| √ | 8. Mongoose V Processors | Synova/ Honeywell | | No resets of C&DH since launch. Memory bit errors exist, but are mapped out from future use. Subject to radiation dose damage. Rated for radiation dose >> 100 krads. With S/C shielding of 40 mils, radiation degradation not manifest as of Sept 15 2016 |
| √ | 9. ACDS & PSE | | | Common design/parts with MAP S/C that have radiation tolerance of 30 krad. With 50 mils box shielding plus 40 mils S/C shielding, for total of at least 90 mils, radiation degradation not manifest as of April 2015. |
| √ | 10. IRU Gyros | Litton | SIRU | Contains 3 HRG (non-rotating gyros). Not wear-out critical. Bias not accelerating and stable. Rated for 15 krads radiation dose. With S/C plus box shielding totaling 120 mils, radiation degradation not manifest as of April 2015. |
| √ | 11. Propulsion Thrusters | Aerojet (Olin) | MR-103G | Incorporates dual coil dual seat valves in series to mitigate risk of valve leakage. Thrusters qualified to 745,000 pulses, which equates to 745,000 sec of burn time, and propellant throughput of 112 lbm. EO-1 liftoff propellant load of 49 lbm used to maintain formation flying with L-7 until October 2007 when EO-1 left formation. All remaining Hydrazine used to maintain MLT at 10AM until February 2011 when attitude control anomaly indicated low fuel pressure condition. No further MLT maneuvers have been attempted. Remaining fuel estimated at less than 3% of launch load and is reserved for debris avoidance maneuvers for rest of mission. Thrusters used 10 May 2014 to avoid close approach with Fengyun 1C debris and performed nominally for 10 seconds to maneuver out of the way. Short duration burns are only length under consideration for debris avoidance as of April 2015. |
| √ | 12. ALI Aperture Cover | MIT/LL | | Actuated by two-phase stepper motor. If motor fails, cover kept in open position by spring. Operations change would be needed to obtain dark calibrations. No indications of degradation or off-nominal performance as of April 2015. |
| √ | 13. WARP | | | No errors on bulk memory. Any radiation induced SEU's most likely correctable. |
| √ | 14. XPAA | Boeing | | No known lifetime critical features. |
| √ | 15. Hyperion CryoCooler | TRW | | Cold head temperatures are stable at about 110K and the Motor Drive trend data indicates a high level of stability matching at launch performance. Cryocooler de-icing is still executed every 2 weeks for 15 hours to offset the failure of the positive stroke sensor the first year after launch even though trends indicate that time between de-icing's could be extended without impact on cryocooler performance. |

√ - Fully assessed and considered not to be life limiting.

# EO-1 Flight Systems

- Health and Safety of spacecraft (S/C) and subsystems continuing nominal operations
- Power Systems are working nominally
  - Had two recent anomalies for differential voltage. EO-1 VT is now set to a VT level 3.0 to reduce the charge rate and thus reduce stress on battery.
  - The two anomalies indicated in two separate cells in the 22 cell NiCD battery
- 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 longer doing lunar calibrations to prevent further future battery issues

# 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).
- EO-1 developed method to perform debris avoidance maneuver if necessary
  - Burned once last May 10, 2014 for 10 seconds

# 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 Mission Enhancements

- **EO-1 32K TDRS supports**
  - EO-1 FOT enhanced the way TDRS passes were used previously by adding 32K TDRS supports
    - All TDRS supports previously were at a slower 4K RTN rate.
    - With faster 32K RTN TDRS supports, EO-1 passes can downlink data much faster compared to the 4K supports.
    - EO-1 FOT is working on modifying goal upload logic so that goals and sensor-webs can be uploading by ground automation during 32K TDRS supports thus increasing imaging and house keeping capabilities.
    - Requested White Sands to add 32K RTN TDRS related SSC codes in SNAS. With dedicated SSC codes, the EO-1 FOT can now quickly schedule 32K TDRS supports
      - All 32K RTN TDRS related SSC codes have been added for the EO-1 mission.

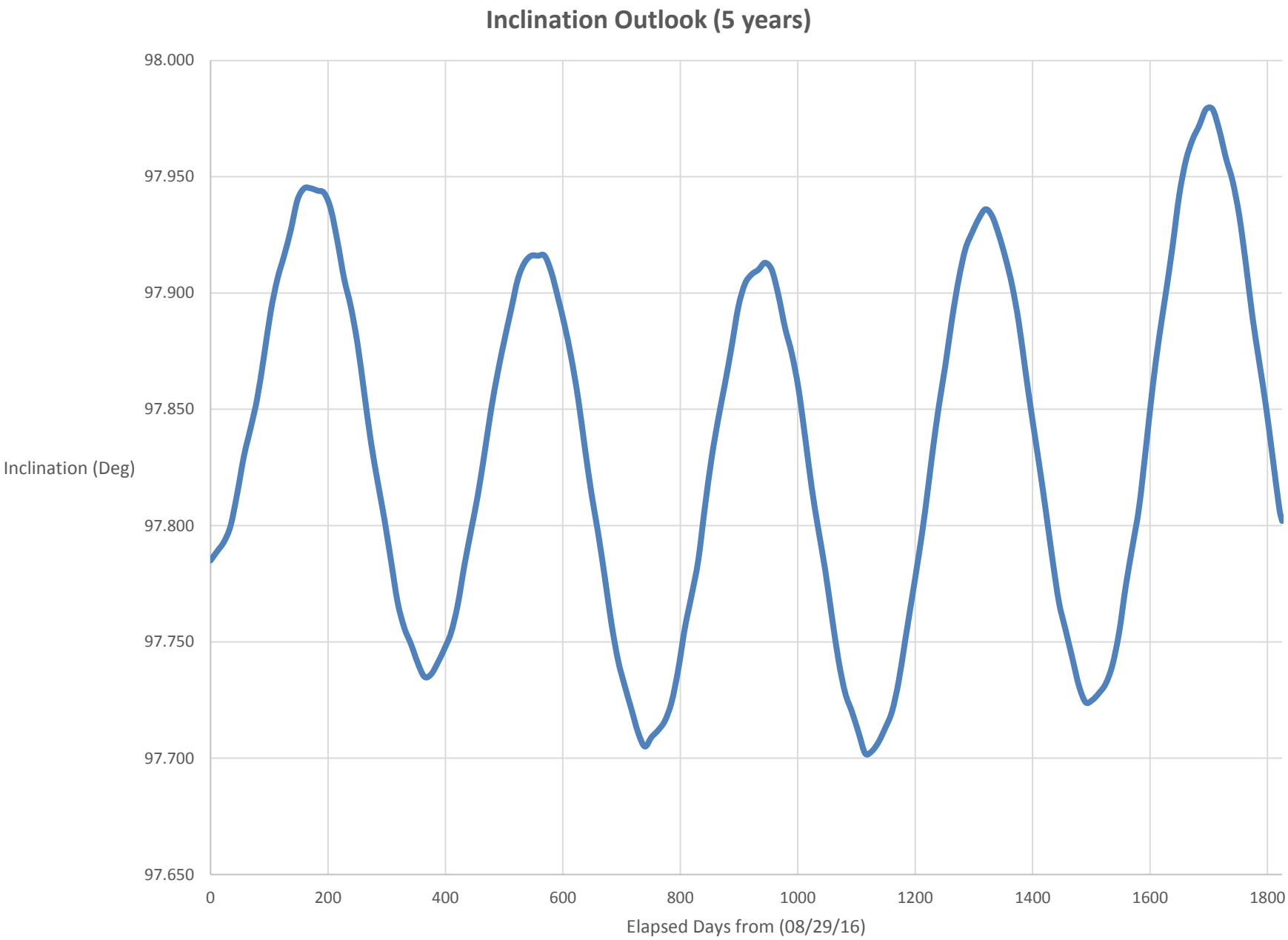
# EO-1 New Ground Stations

- 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 USN USAK-~~02/03/04~~ 03 operational, USAK 04 testing, USAK 05 next
  - 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
  - AS1 almost completed testing and AS3 operational (NASA assets operated by Harris under Univ. of Alaska contract

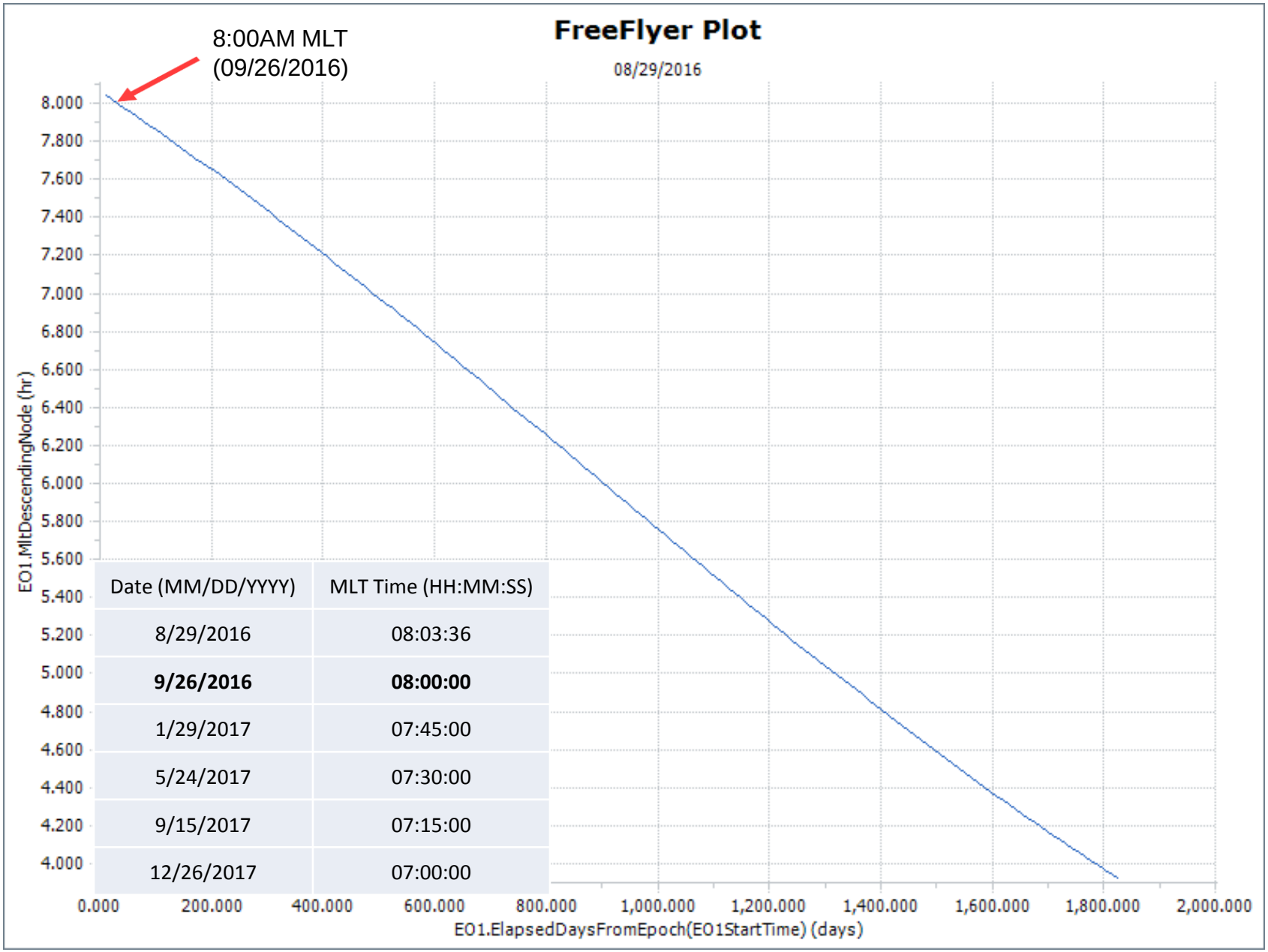
# EO-1 Orbital Information

- EO-1 Orbit Information on 03/13/15 00:00:00z
  - Semi-major Axis = 7060.532 Km
  - Eccentricity = 0.000605
  - Inclination = 97.781 Deg
  - RAAN = 278.325 Deg
  - Argument of Perigee = 15.889 Deg
  - True Anomaly = 319.396 Deg
  - Altitude at Apogee = 678.123 Km
  - Altitude at Perigee = 678.123 Km
  - Period: 5904.282 sec

# Earth Observing-1 Inclination Status for the MOWG



# MLT Projections as of 08/29/16




| Date (MM/DD/YYYY) | MLT Time (HH:MM:SS) |
|---|---|
| 8/29/2016 | 08:03:36 |
| **9/26/2016** | **08:00:00** |
| 1/29/2017 | 07:45:00 |
| 5/24/2017 | 07:30:00 |
| 9/15/2017 | 07:15:00 |
| 12/26/2017 | 07:00:00 |

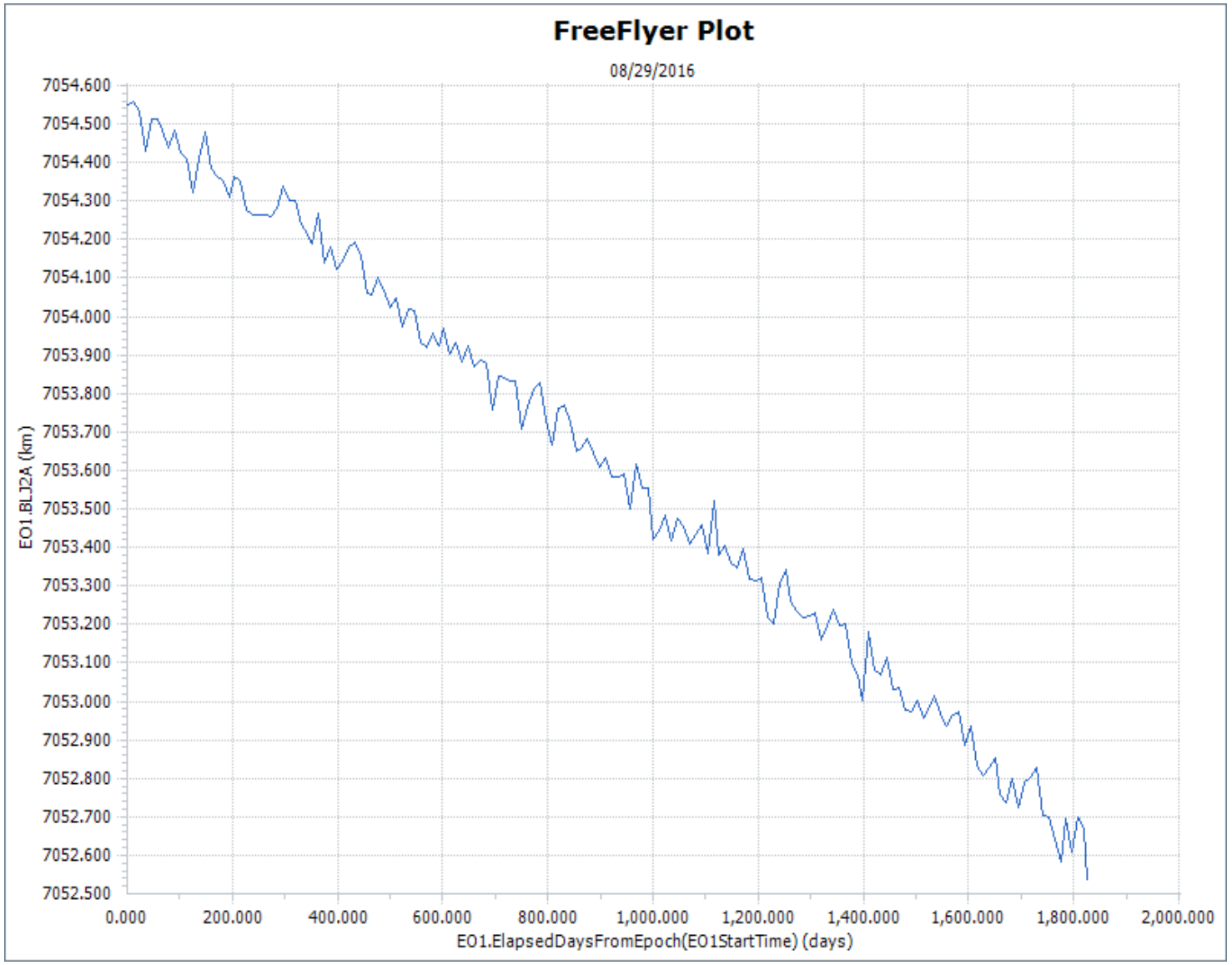
# ALI data taken at an 8 AM equatorial crossing time is valuable in spite of the decline in SNR

- 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 projected to reach 8 AM crossing time until Sept 26, 2016.

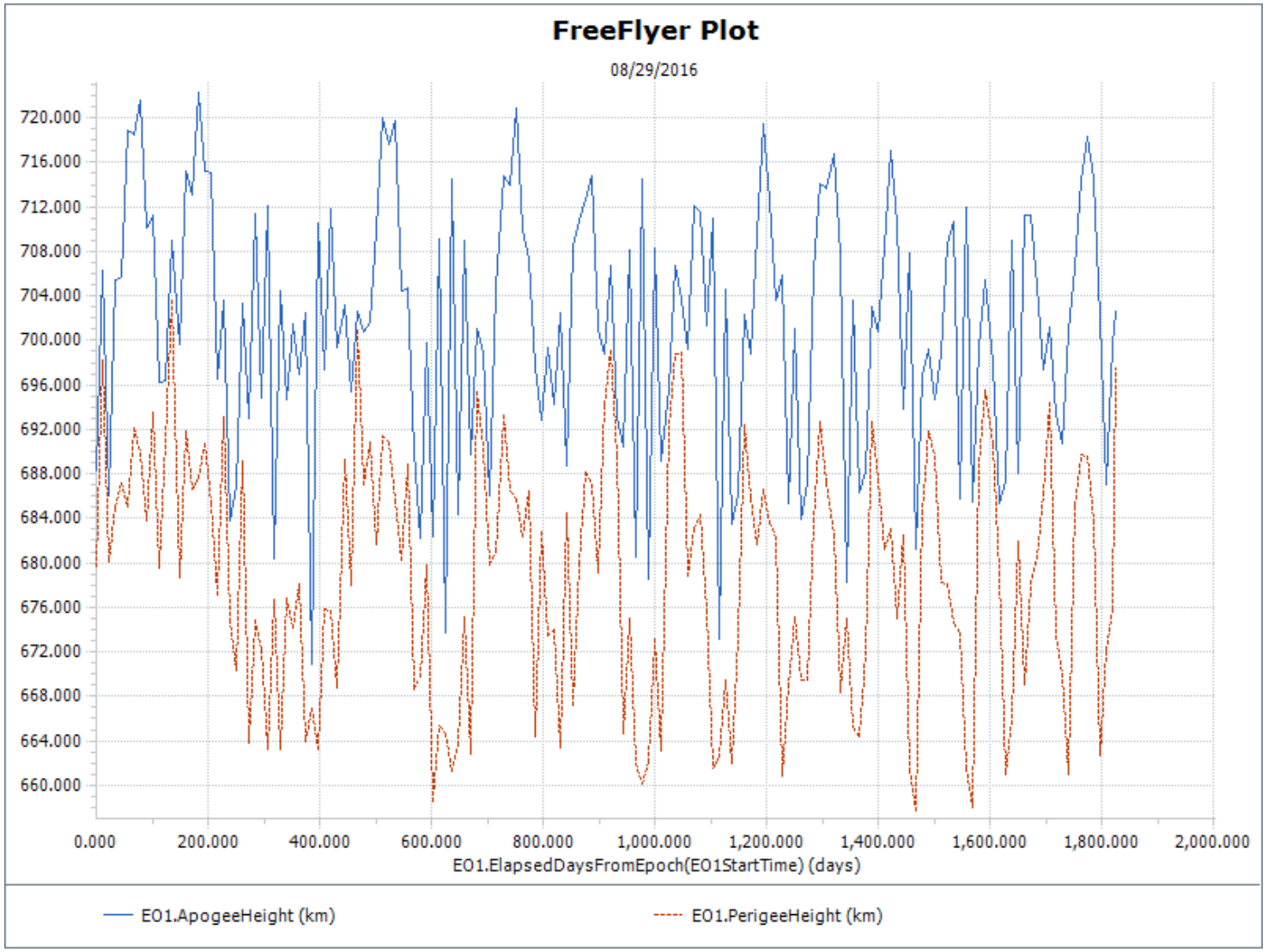
| Crossing Time at Equator | March 22 | | June 22 | | September 22 | | December 22 | |
|---|---|---|---|---|---|---|---|---|
| | Elevation (degrees) | cos(SZA) | Elevation (degrees) | cos(SZA) | Elevation (degrees) | cos(SZA) | Elevation (degrees) | cos(SZA) |
| 8:00 AM | 28.3 | 0.47 | 26.9 | 0.45 | 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
# (0.00 = 29 August 2016)



# EO-1 Orbit Plots 5 Year Outlook
# Apogee and Perigee Altitude
# (0.00 = 29 March 2016)



# EO-1 Ground Systems

- All four Telemetry & Command (T&C) strings working nominally
  - Successfully performed a contingency test utilizing Backup Front End Data System and the 4th String T&C system with both ground station and TDRS
- Front End Data Systems primary and backup working nominally
- Data Processing primary and backup working nominally
- Housekeeping Telemetry Processing primary and backup working nominally

# EO-1 Ground Systems

- Flight Dynamics primary and backup workstations functioning nominally
  - Added TR2 tracking data parameters to allow TR2 tracking data file (TDF) processing (AS1, AS3, USAK04 and USAK05)
  - AS3 certified, others in process
- Mission Planning primary and backups (both ASPEN and ASIST SCP) working nominally
- Central File Hub primary and backup working nominally
  - Continuing to add more incoming file transfers to the Central File Hub, and removing the previous path as they are tested successfully
  - AS, AK delivery through Central File Hub

# EO-1 Mission Closeout Status as of 9-15-16

- Proposed full year of operations during FY2016 with decommissioning starting October 2016, completed March 31, 2017
- Phase F report completed June 18, 2016, sent to HQ and no comments received
- Letter of Termination from NASA HQ 8/31/16 (not received yet)
- EO-1 Archive Assembly for transfer to Code 400 Share Point and National Archive
  - Established Spaces (Code 580) server to collect mission documentation, request for access should be sent to Dan Mandl
  - Formatted into folders compatible with Code 400
  - Plan to resort into National Archive compatible format in separate section of Spaces once transfers complete
  - Began to transfer documents to Spaces from SEUNMP Library Documents for EO-1
    - There are approximately 1060 documents of which approx. 390 transferred to Spaces or on Mandl's PC for preparation to transfer to Spaces
  - Estimated documents needed for archive in addition to SEUNMP Library is TBS

# EO-1 Mission Closeout Status as of 9-15-16

- EO-1 Final Report
  - Generated preliminary outline (will distribute for comment mid Sept 2016)
  - Attempting to include many links to other documents to technical details to make end of mission report compact
- Phase F Plan – status
- End of Mission Plan (targeting GSFC management signatures by Sept 30, 2016)
  - Submitted to COMET (CM system in Code 428)
  - Previewed by Paul Brandinger (Code 420) - comments
    - Need to confirm that Code 500 invited for final test
    - How are we going to pull together decommissioning review
- Invitation to AETD to use EO-1 as experimental platform in January 2017 was initiated and presently at Code 580 Division (Sept 4, 2016) with next step to Code 500 director …for distribution to Code 500
- Ground freeze set for Oct 1 2016
  - Except flight software lab

# EO-1 Mission Closeout Status as of 9-15-16

- Decommission Review approx. January 10, 2017
  - Chaired by ESMO
  - Participation by Code 300, Code 400 and Code 500 , including all Earth Science Mission Directors
- Dispose fuel begin Jan 11, 2017 to February 11, 2017
- NASA HQ Decision to Terminate Mission, Key Decision Point, KDP-F Jan 24, 2017
  - Meeting at HQ to summarize decommissioning review and gain concurrence by HQ to decommission
- Technology testbed activities on EO-1 such as firing of PPT and SC Security tests January 2017
- Disposal Readiness Review approx. Feb 13, 2017
  - At GSFC, Mission Directors panel approves final flight load uplink
- Execution of Passivation Procedures approx. Feb 22, 2017
- Facilities disposal March/April 2017

# EO-1 Flight SW Lab Status

- Original intent was to use Flight SW Lab to check out the RTS patches
- Mongoose 5 breadboard is marginal and appears to have hardware problems.
- Looking into possibility of using alternate Mongoose box originally fabricated for JPL to use in testing ASE
- Otherwise all simulations will have to be table top reviews via source code
- Plan B to test the ability to load a no op RTS and thus at least prove that we can load and execute RTS updates