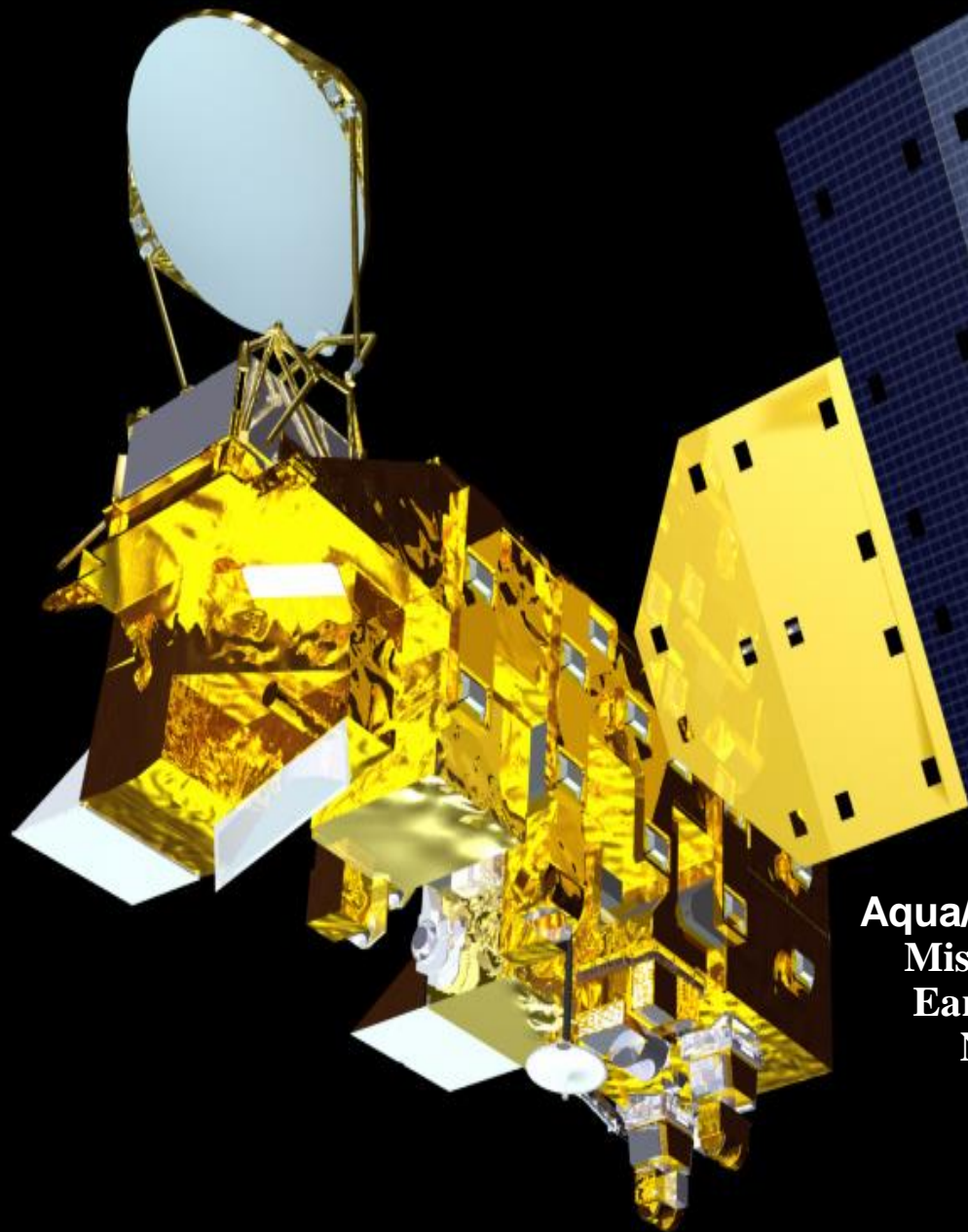


EOS Aqua



Mission Status at Earth Science Constellation MOWG Meeting @ LASP

April 13, 2016

Bill Guit

Aqua/Aura Mission Director - Code 584/428
Mission Validation and Operations Branch
Earth Science Mission Operations Project
NASA/Goddard Space Flight Center

William.J.Guit@nasa.gov



Topics



- **Mission Summary**
- **Spacecraft Subsystems Summary**
- **Recent & Planned Activities**
- **Inclination Adjust Maneuvers**
 - Spring 2017 Draft Calendar
 - Long-Term Plan (in EOS Flight Dynamics Presentation)
- **Propellant Usage & Lifetime Estimate**
- **Mission Summary**
- **Additional Slides:**
 - Orbit Maintenance Maneuvers
 - Conjunction Assessment High Interest Events
 - Ground Track Error & Mean Local Time History
 - Spacecraft Orbital Parameters Trends & Predictions



EOS Aqua Mission Summary

(Updates since June 2015 Meeting at GSFC)



- **05/04/02: Launch**
 - 6-Year Design Life
- **12/02/08: End of Prime Mission Review**
- **07/22/13: Submitted Phase F Study**
- **03/03/15: Senior Review Proposal #5**
 - Reliability Estimates thru 2022
 - Consumables through 2021
- **05/04/15: Aqua 13-Year Anniversary**
- **06/22/15: 2015 Mission Extension Senior Review Proposal Panel Report**
 - #1 Ranked Earth Science Mission
 - Mission extension through FY19
- **12/08/15: End of AMSR-E Operations**
- **01/27/16: ESMO Annual Review #9**

National Aeronautics and Space Administration

Aqua

Senior Review Proposal

Dr. Claire L. Parkinson, Aqua Project Scientist
NASA Goddard Space Flight Center

Dr. Lazaros Oreopoulos, Aqua Deputy Project Scientist
NASA Goddard Space Flight Center

Dr. Joao Teixeira, AIRS/AMSU/HSB Science Team Leader
NASA Jet Propulsion Laboratory

Dr. Roy Spencer, AMSR-E Science Team Leader
University of Alabama in Huntsville

Dr. Norman G. Loeb, CERES Science Team Leader
NASA Langley Research Center

Dr. Michael D. King, MODIS Science Team Leader
University of Colorado

Wynn Watson, Earth Science Mission Operations
NASA Goddard Space Flight Center

Submitted to NASA Headquarters, March 3, 2015

2/19/2015 AIRS image 2/2/2015 MODIS image 3/2013 CERES image 9/17/2007 AMSR-E image



Aqua Spacecraft Subsystems

All subsystems configured to primary hardware

Changes since June 2015 MOWG at GSFC are in blue



- **Command & Data Handling (CDH) – Nominal**
 - Solid State Recorder (SSR) – only holds 2 orbits of data
 - *SSR Ops Error Anomaly (12/2/07) – fully recovered 1/28/09*
- **Communications (COMM) – Nominal**
- **Electrical Power System (EPS) – Nominal**
 - *Array Regulator Electronics (ARE) 4A (9/8/04 – self-recovered)*
 - » *Re-occurred 1/11/10 and 7/18/13 (2 strings)*
 - *ARE-6C (3/1/13) – post-anomaly investigation indicated 10/20/11 also*
 - » ***Numerous power drops since 10/20/11 with last on 11/04/15 (6 strings)***
 - *Previous ARE Anomalies:*
 - *ARE-1C (11/8/10 – 1 string) & ARE-3A (2/14/12 – 1 string) and ARE-4C (4/26/15 – 3 strings)*
 - » ***Estimated that Aqua has lost 13 strings of solar cells out of a total of 132 strings***
 - » ***Aqua continues to have significant power margin where the life limiting item is fuel***
 - *Battery Cell Anomaly (9/2/05)*
 - *Solar Panel #8 Thermistor #6 Failure (8/3/09)*
 - *Solar Array Offset (Reported 11/17/09, Corrected 6/29/10)*
- **Flight Software (FSW) – Nominal**
- **Guidance, Navigation & Control (GN&C) – Nominal**
- **Propulsion (PROP) – Nominal**
 - *Dual Thruster Module (DTM-2) Heater Anomaly (9/8/07)*
- **Thermal Control System (TCS) – Nominal**



Recent Activities

(June 2015 – March 2016)



- **20 CARA High Interest Orbital Debris Events (June 2015 – March 2016)**
 - 6 that required significant action (Tier 3 + Tier 4) plus 8 additional Tier 2 HIEs
 - 3 RMM/DAMs PLANNED – 2 APPROVED/WAIVED-OFF – 1 EXECUTED
 - 3 Planned routine drag make up maneuver postponed and rescheduled
 - **CARA Tier 4 HIE on 12/16/2015 represents interesting case study**
 - » came on the heels of 11/18 Tier 4 Postponement, Potential post-maneuver conjunction of concern required re-planning of routine DMUM, Risk rose to CARA RED level and planned/modified routine DMUM consider a RMM/DAM, Post maneuver conjunction risk rolled off and maneuver was successfully executed
- **1 Instrument Anomaly – 1 minor ongoing spacecraft bus anomaly**
 - 11/04/2015: ARE-6C Power Drop Anomaly – multiple times throughout the past few years
 - 12/04/2015: AMSR-E Antenna Spin Down Anomaly (4-days prior to planned spin-down)
- **Spacecraft Delta-V Maneuvers: 9 Routine DMUMs, 3 of 4 IAMs and 1 DAM/RMM**
 - **9 Routine Drag Make-Up Maneuvers (DMUMs): All without yaw slews**
 - » 2015: 7/02, 7/29, 9/03, 9/25, 10/15, 11/20 and 12/16, 2016: 01/07 (#105), 02/11 (#106), ... (Maybe another?)
 - **3 Inclination Adjust Maneuvers (IAMs):**
 - » 2016: 3/9 (#48), 3/16 (#49) and 4/6 (#50) – one more to complete #51 on 4/21
 - **1 Debris Avoidance Maneuver (DAM): 12/16/2015**
- **10 Instrument Calibration Maneuvers (Monthly MODIS Lunar Calibration)**



Planned Activities

- **Complete 2016 Inclination Adjust Maneuvers (IAMs)**
- **Mid-May 2016: Drag Make Up Maneuver (DMUM) # 107**
- **Fall 2016: Earth Science Constellation(ESC)/A-Train MOWG**
 - Update propellant budget, decommissioning analysis, reliability predictions,...
- **----- 2017 -----**
- **January 2017: Flight Operations Annual Review (#10)**
- **February 2017: Senior Review Proposal #6**
- **Spring 2017: Afternoon Constellation Science Meeting (?)**
- **Spring 2017: Earth Science Constellation(ESC)/A-Train MOWG**
- **Spring 2017: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)**
 - 4/5/2017 (#52), 4/12/2017 (#53), 4/26/2017 (#54) & 5/3/2017 (#55) – Backup 5/10
- **Long-Term Plans**
 - Continue to improve Debris Avoidance Maneuver (DAM) responsiveness
 - Automation of Routine Operations
 - Possible Re-fueling Mission



Collision Risk Management Process Improvements



In response to the constantly increasing number of predicted close approaches with orbital debris and operational satellites (High Interest Events – HIEs – see slides 18 & 19) and anticipated updates to the DOD’s Space Fence and size of the Space Catalog (20K → 150-200K)

ESMO is in the process of developing new ground system capabilities to autonomously identify and optimize Debris Avoidance Maneuver (DAM) planning options in a significantly reduced amount of time (essentially fully-automated end-to-end and continuously 24x7)

Collision Risk Management System (CRMS) capabilities include:

- **Goal is to develop a fully automated debris avoidance maneuver planning and maneuver screening process**
- **User defined and modifiable collision risk thresholds**
 - **Probability of collision, miss distances and time to TCA**
 - **Post-maneuver probability of collision**
- **Handles multiple secondary object conjunctions & repeaters**



DRAFT Spring 2017 Inclination Adjust Plan




Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
19 March	20	21	22	23	24	25
26	27	28	29	30	31	1 April
2	3	4	5 Aqua IAM #52	6 Aura IAM #49	7	8
9	10	11	12 Aqua IAM #53	13 Aura IAM #50	14	15
16 Easter	17	18	19 Spring Break	20 Spring Break	21	22
23	24	25	26 Aqua IAM #54	27 Aura IAM #51	28	29
30	1 May	2	3 Aqua IAM #55	4 Aura IAM #52	5	6
7	8	9	10 Aqua Backup	11 Aura Backup	12	13
14	15	16	17	18	19	20



Aqua Propellant Usage (September 2014)



- **2006: Initial Aqua lifetime fuel analysis**
- **2008: Detailed Aqua & Aura lifetime analyses**
 - Presented to A-Train MOWG and at Aqua End of Prime Mission Review in December 2008
- **September 2012: Initial Aqua Decommissioning Plan**
 - Updated Lifetime Estimates
- **August 29, 2013: Updated Decommissioning Plan**
 - Updated definitive fuel usage and predicted solar flux levels
 - Updated propellant estimates for IAMs & DMUMs
 - Updated Constellation Exit Plan
 - Safely exiting the Afternoon Constellation requires that Aqua's final apogee be at least two kilometers below the minimum perigee of the other constellation members (692 km target)
 - Perform orbit lowering maneuvers centered at apogee and perigee (pairs of maneuvers)
- **September 30, 2014: Updated Decommissioning Plan**
 - Updated definitive fuel usage and predicted solar flux levels
 - Updated propellant trends for IAMs & DMUMs
- **Annual updates provided each September**
 - Final produced 60 days before start of decommissioning
- **September 2015 Update was delayed to allow additional time to evaluate long-term plan (See next few slides)**
 - **See Flight Dynamics Long-Term Plan**



Flight Dynamics Support Services
FDSS-1012-0004
CODE 595


Flight Dynamics (FD)
Task Order 1012
TECHNICAL MEMORANDUM
Updated Analysis for Aqua Decommissioning

Issue Date: September 30, 2014

Prepared by:
Ryan Moore
EOS FDS, Building 32
a.i. solutions, Inc.

Submitted by:
Jeff Dibble
EOS FD Domain Lead
a.i. solutions, Inc.
Lanham, MD

a.i. solutions, Inc.
10001 Derekwood Lane, Suite 215
Lanham, MD 20706



a.i. solutions



Remaining Fuel Estimate (Fall 2015)



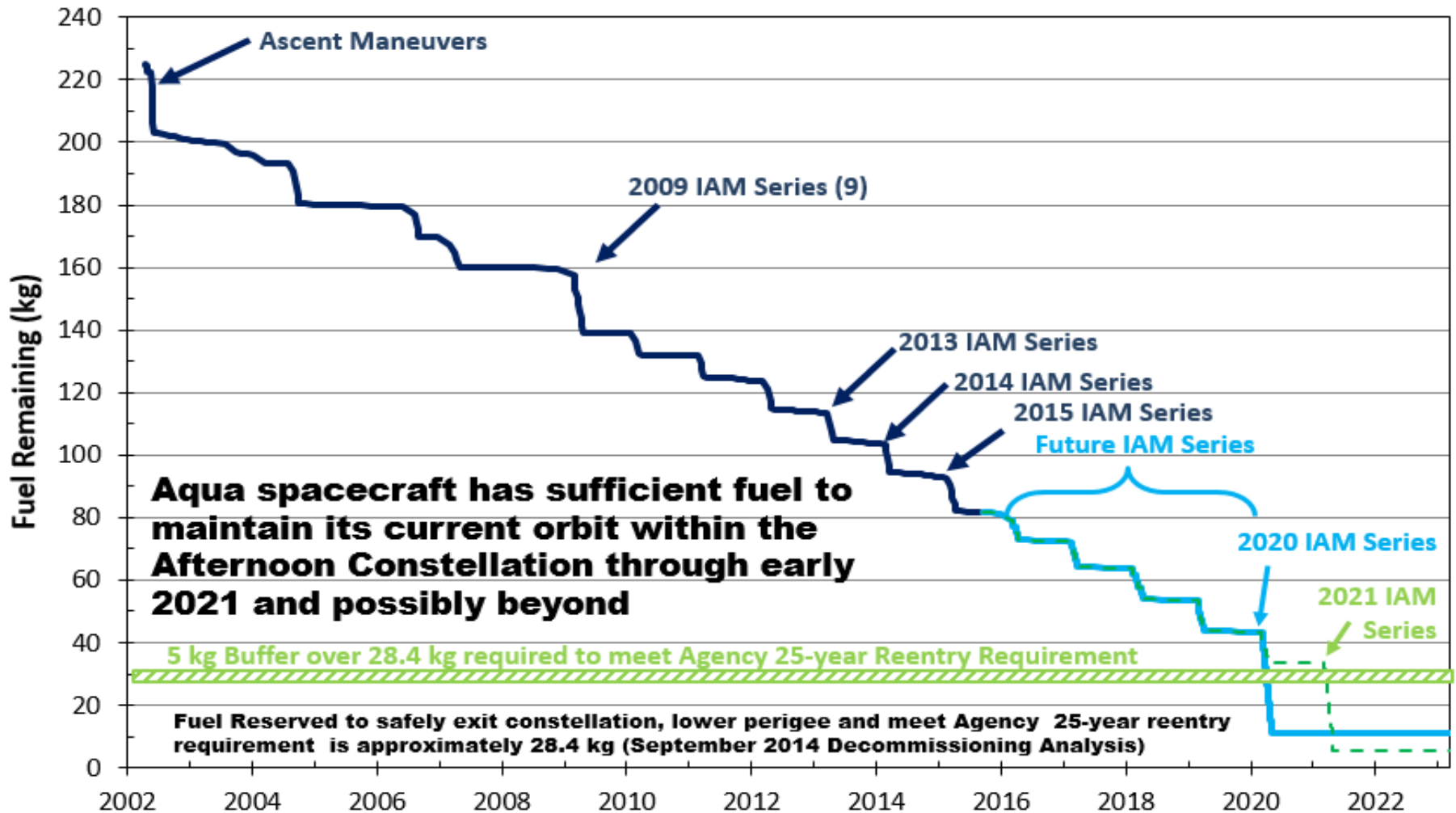
- **Long-term orbit simulations were run for Aqua through 2021/2022**
 - **Used mean nominal Schatten solar flux predictions**
 - **Estimated the frequency of drag make-up maneuvers (DMUMs) to maintain Aqua's WRS-2 ground track requirements**
 - **Estimated the required number of annual inclination maneuvers (IAMs) for Aqua to maintain it's mean local time (MLT) requirement**
 - **Did not include potential debris avoidance maneuvers**
 - **Utilized FreeFlyer 6.7.2 which incorporated the solid earth tide model allowing greater accuracy for long term predictions of inclination, beta angle, and mean local time**
- **Lifetime predictions for Aqua show that the spacecraft will have sufficient fuel to maintain its current orbit within the Afternoon Constellation through early 2021 and possibly beyond**
- **Analyses are updated annually by EOS Flight Dynamics Team after each series of inclination adjust maneuvers**
 - **Next full update: September 2016**



Fuel Usage: Actual & Predicted (February 2016)



----- Aqua Definitive Data - - - - - Aqua Predicted - - - - - Constellation Exit





Debris Assessment Software

(September 2014)



- **The Debris Assessment Software (DAS) was created by the Orbital Debris Office in Johnson Space Center and is the Agency standard for end of mission life analyses and lifetime estimations**
 - Current Version 2.0.2
- **DAS requires several inputs from a user describing a spacecraft's mission:**
 - The operational orbit parameters
 - The mission launch date
 - Length of a mission's lifetime
- **In turn, DAS outputs:**
 - If the mission is compliant with NASA requirements for limiting orbital debris
 - A recommended apogee and perigee that will allow the spacecraft to reenter within a specific period and satisfy the NASA requirements
- **Aqua will have enough fuel onboard to safely exit the constellation and de-orbit to the DAS recommended perigee out through the 2021 time frame**

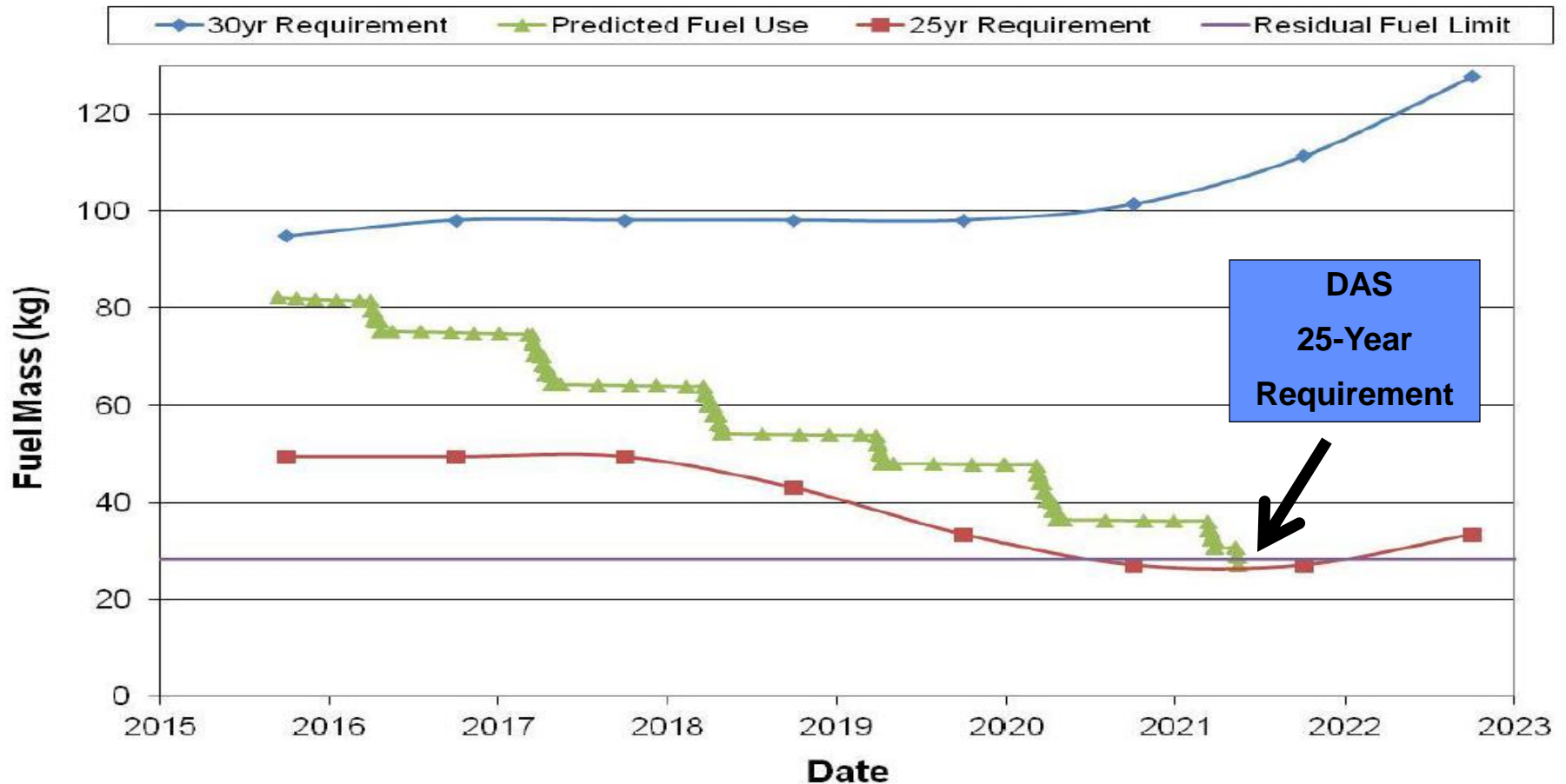
No Changes or Updates



Aqua DAS End of Life Predictions (September 2014) **No Changes or Updates**



Aqua Required Fuel Nominal Solar Flux Predictions and Operational Reentry Area

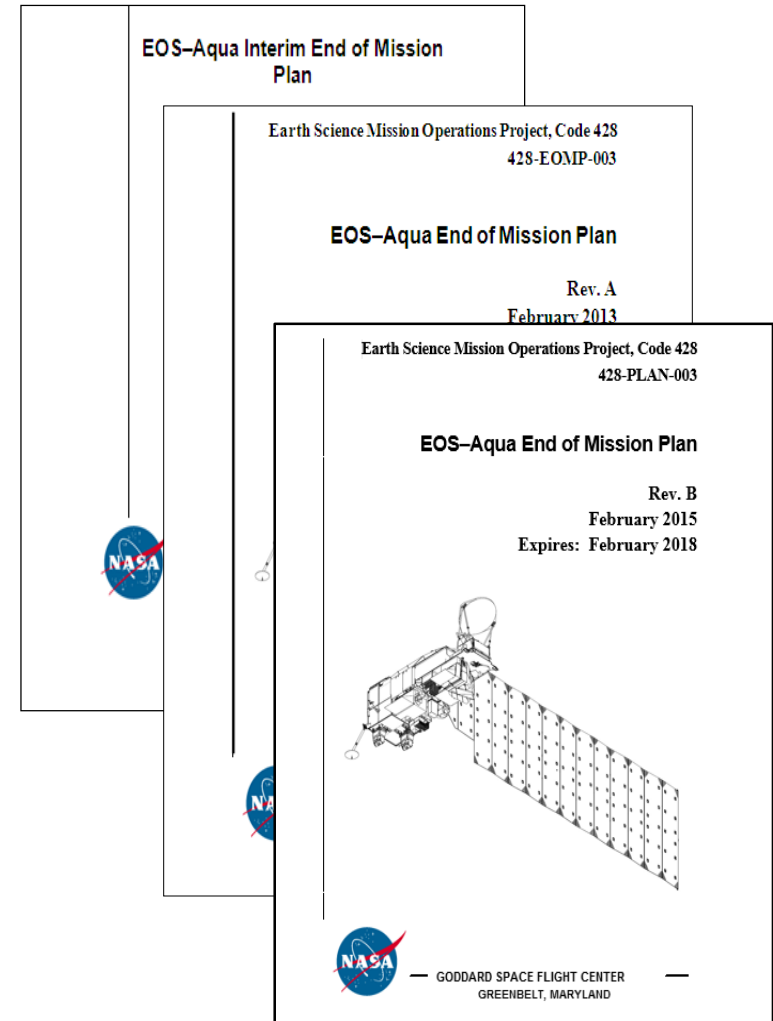




Changes since last ESC MOWG Aqua End of Mission Plan



- Initial draft February 2009
- Produced the first “Interim” End of Mission Plan (EoMP) in May 2011
 - Approved by NASA HQ July 2011
- End of Mission Plan (Rev A): February 2013
 - Updated Lifetime Estimates (09/2012)
 - Added Small Object Collision Assessment
- End of Mission Plan (Rev B): February 2015
 - Final will be produced 60 days before EoM
 - Latest Annual Lifetime Estimate (09/2014)
 - Synopsis
 - » Safely exit the A-Train Constellation
 - » Passivate Aqua to the extent possible for uncontrolled reentry
 - » Aqua has **five (5)** approved waivers for passivation
 - Pressurant Passivation
 - Large Object Collision Probability
 - Small Object Collision Probability
 - Orbital Lifetime (30-Year)
 - Re-entry Risk (Un-controlled)
 - » **Waivers were approved in May 2013**
- **Next End of Mission Plan (Rev C): Feb 2017**





Summary



- **Spacecraft Status - GREEN**
- **Instrument Status - GREEN**
 - **AIRS, AMSU, CERES & MODIS:**
 - » **Operations Nominal – Producing Great Science**
 - **HSB: Survival Mode since 2/5/2003**
 - **AMSR-E: Antenna Anomaly & Spin Down to 0 RPM on 10/04/2011**
 - » **12/04/2012: Spun-Up to ~2 RPM**
 - » **12/04/2015: Antenna Spin Down Anomaly #2**
 - » **12/08/2015: End of AMSR-E Instrument Operations**
- **Data Capture/L0 Processing Status – GREEN**
 - **SSR Data Capture to 03/31/2016: 99.97987269+% (2/29/2016)**
- **Data Latency – Excellent**
- **Ground Systems – Responding to new security requirements and upgrades to obsolete hardware or COTS systems, as required**
 - **Automation Effort: CDR 2/2013, Phase II CDR 1/29/2014**
 - **Phase II: Development & Testing 9/1/2015 – 2/3/2016, ORR NET Aug 2016**



Additional Slides

**Orbit Maintenance Maneuvers
Conjunction Assessment High Interest Events
Ground Track Error & Mean Local Time History
Spacecraft Orbital Parameters Trends & Predictions**



Orbit Maintenance

KEY: Updates since last MOWG in blue

- **Mission Requirement:** Perform Drag Make-Up Maneuvers (DMUMs) to maintain Aqua's ground track error (GTE) with respect to the World Reference System (WRS-2) within +/-10 Km at the Descending Node
 - Changed from +/-20 Km with DMUM #19 (1/12/05)
 - To date a total of **106** DMUMs have been performed
 - Variation in performance from -9.3% (cold) to **+24%** (hot)
 - **Last DMUM (#106) performed 2/11/2015 – Next mid-May 2015 (#107)**
- **Control Box Excursions:** To date there have been 4 Control box Excursions
 - 4 on +10km front-side: 11/4/12 to 11/14/12, 10/23/13 to 10/24/13 and 3/6/14 to 3/10/14
 - » 03/16/2015 to 04/02/2015
 - 1 on -10km back-side: 11/07/13 to 12/14/13 (Emergency DAM on 10/24 and DAM on 11/28)
- **Mission Requirement:** Perform inclination adjust maneuvers (IAMs) to maintain the Mean Local Time (MLT) as measured at the Ascending Node between 1:30 and 1:45 MLT (Mission Goal starting in 2011: 13:35:45 +/- 45 seconds)
 - **Performed 47 inclination adjustment maneuvers to date**
 - » Fall 2003 (1), Spring 2004 (1), Fall 2004 (5), 2005 (NONE)
 - » Fall 2006 (4 of 6 - cancelled final 2 burns), Spring 2007 (4 - interrupted 2-weeks),
 - » Spring 2008 – NONE per special request from PARASOL
 - » Spring 2009 (9), Spring 2010 (3), Spring 2011 (3), Spring 2012 (4)
 - » Spring 2013 (4 with #3 being delayed 1-week), Spring 2014 (4), Spring 2015 (5)
 - » **Spring 2016 In Progress (3 of 4 IAMs completed, one to go on 4/20/2016)**



Aqua Conjunction Assessment High Interest Events



(June 2015 – March 2016: 20 CARA HIEs – 6 Required Significant Action)

1. 06/18/2015: CA vs. 37442 at 20:04:48 GMT – DAMs planned, self-mitigated (T3)
2. 07/11/2015: CA vs. 85095 at 00:29:18 GMT – Monitored but no significant action required (T2)
3. 08/12/2015: CA vs. 33854 at 10:05:00 GMT – Monitored but no significant action required (T2)
4. 10/10/2015: CA vs. 21544 at 20:46:33 GMT – Post-maneuver CA caused postponement of 10/8 DMUM (T4)
5. 11/21/2015: CA vs. 34746 at 08:42:13 GMT – DAMs planned, self-mitigated (T3)
6. 11/21/2015: CA vs. 31876 at 10:31:22 GMT – Monitored, complicated other 11/21 conjunctions (T2)
7. 11/21/2015: CA vs. 00253 at 11:13:08 GMT – Postponed planned 11/18 DMUM (T4)
8. 12/16/2015: CA vs. 22475 at 16:16:32 GMT – Re-planned 12/16 DMUM as DAM #_ (T4)
9. 12/18/2015: CA vs. 36676 at 10:00:30 GMT – Monitored, complicated 12/16 DMUM (T2)
10. 01/09/2016: CA vs. 36088 at 09:03:47 GMT – SJ-11-01 CA with small radial miss, monitored, no action required (T2)
11. 01/16/2016: CA vs. 36676 at 16:11:54 GMT – Short-notice, requested MTS Plot for Sat 1/16 DAM, self-mitigated (T2)
12. 02/09/2016: CA vs. 82440 at 10:03:54 GMT – Monitored but no significant action required (T2)
13. 02/12/2016: CA vs. 33503 at 13:29:43 GMT – Monitored but no significant action required (T2)
14. 02/26/2015: CA vs. 35970 at 05:25:29 GMT – RED HIE, DAMs planned, self-mitigated (T3)

Aqua Summary: 20 CARA HIEs (6 Tier 1, 8 Tier 2, 3 Tier 3 and 3 Tier 4)

3 DAMs Planned, 1 DAM Executed, 2 DAMs that self-mitigated,

0 DAMs that were approved and waived-off

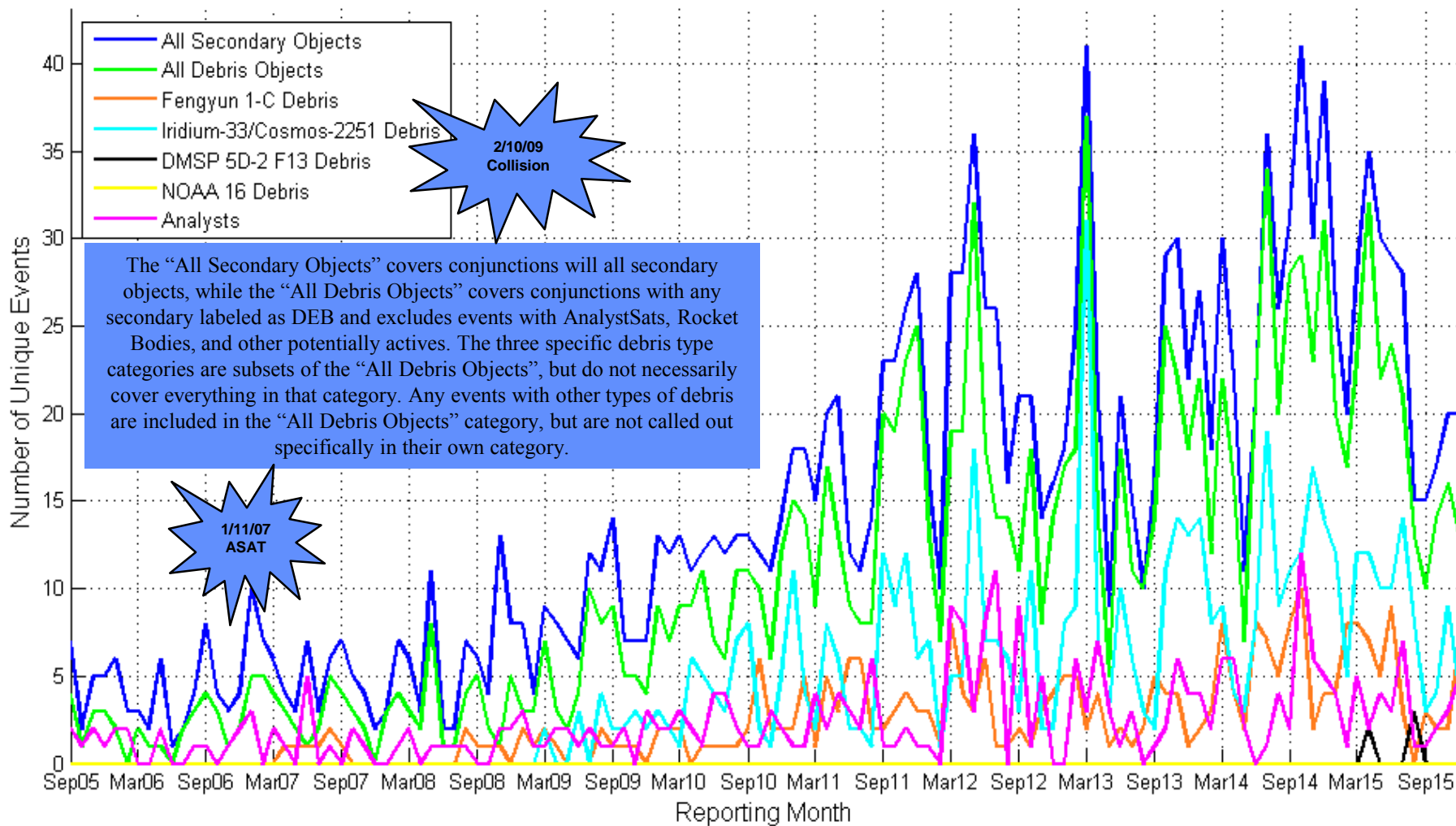
3 Routine maneuver was postponed and rescheduled



Aqua Conjunction Assessment Statistics



(September 2005 thru December 2015)

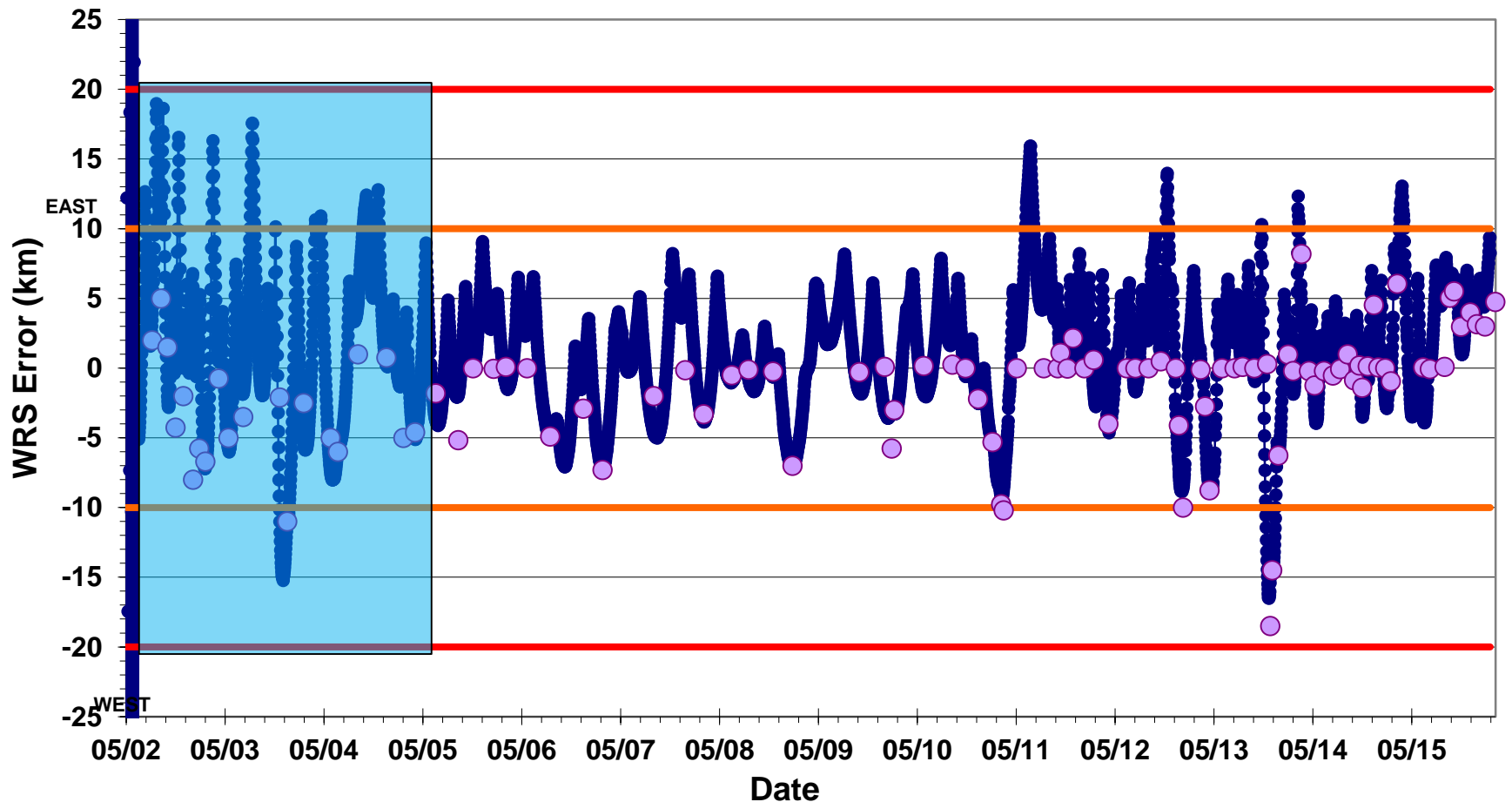


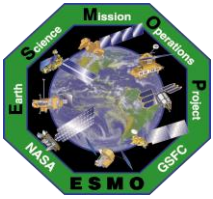


WRS Ground Track Error (GTE) (As of Feb 16, 2016)



Aqua WRS Groundtrack Error at the Descending Node
(Maneuver planning targets included)



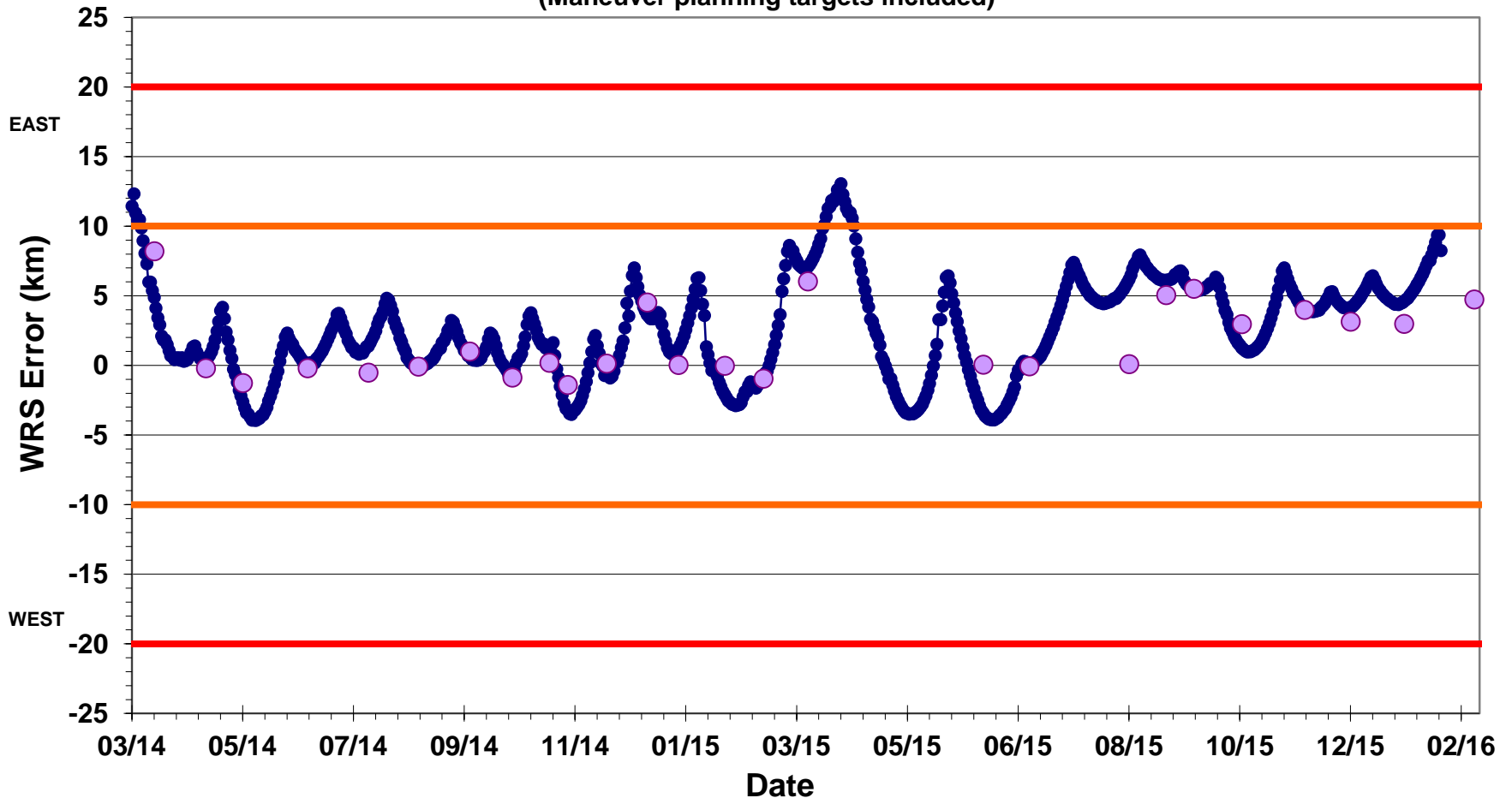


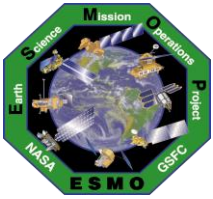
WRS Ground Track Error (GTE)

(As of Feb 16, 2016)



Aqua WRS Groundtrack Error at the Descending Node
(Maneuver planning targets included)

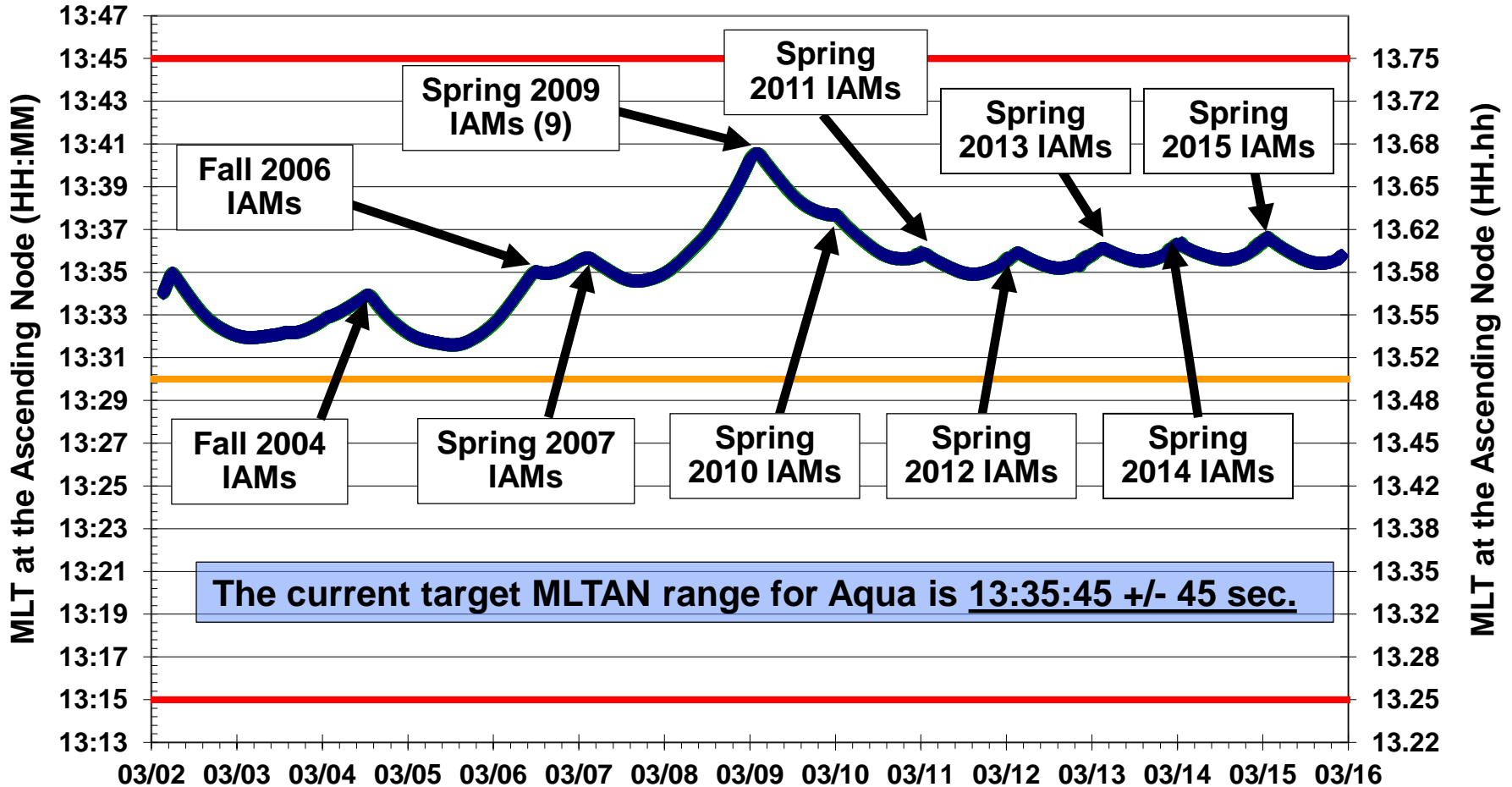




Aqua Averaged MLT @ Ascending Node (As of Feb 16, 2016)

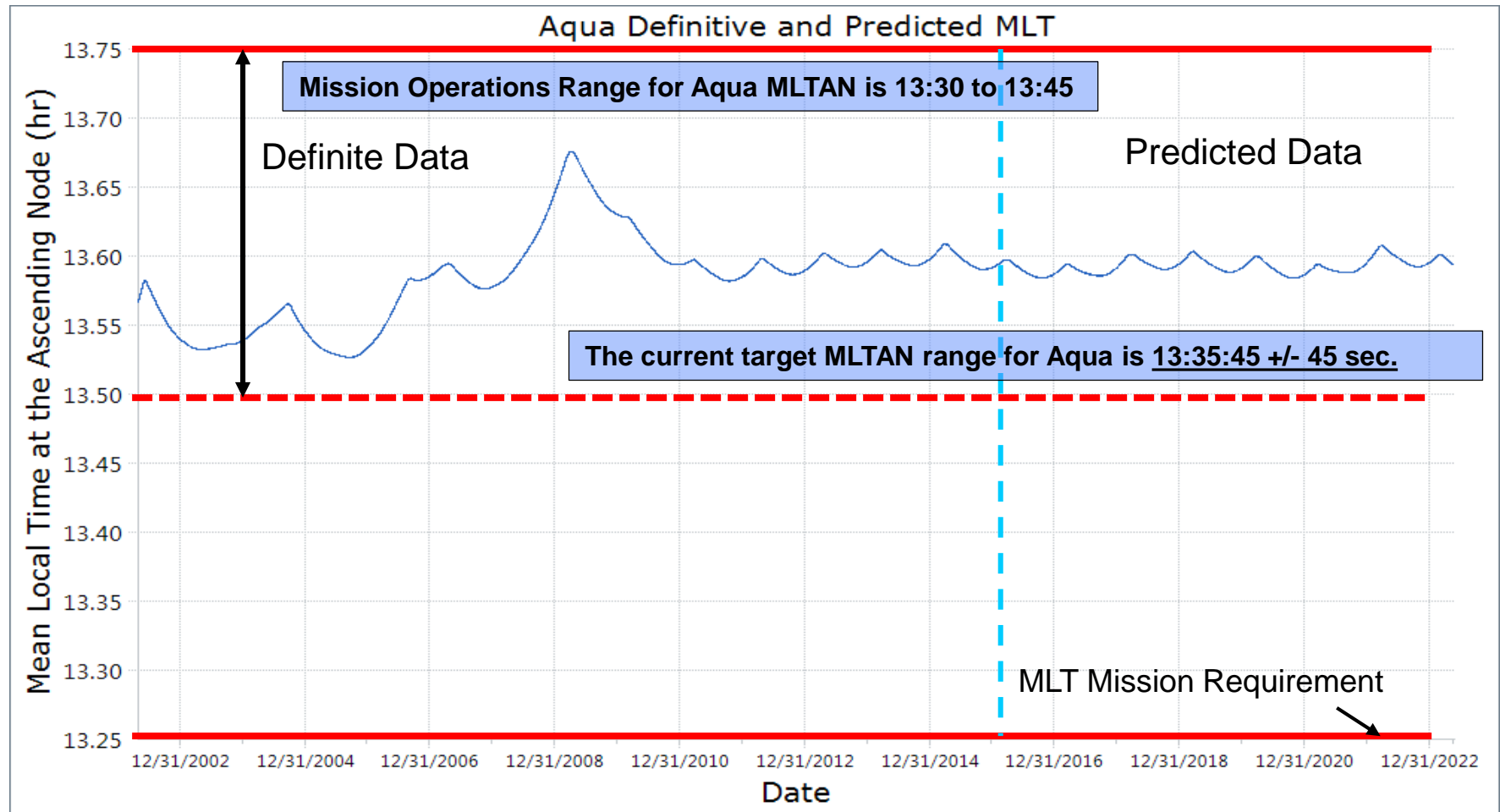


Aqua Averaged Mean Local Time at the Ascending Node





Aqua MLT @ Ascending Node (as of Feb 16, 2016)





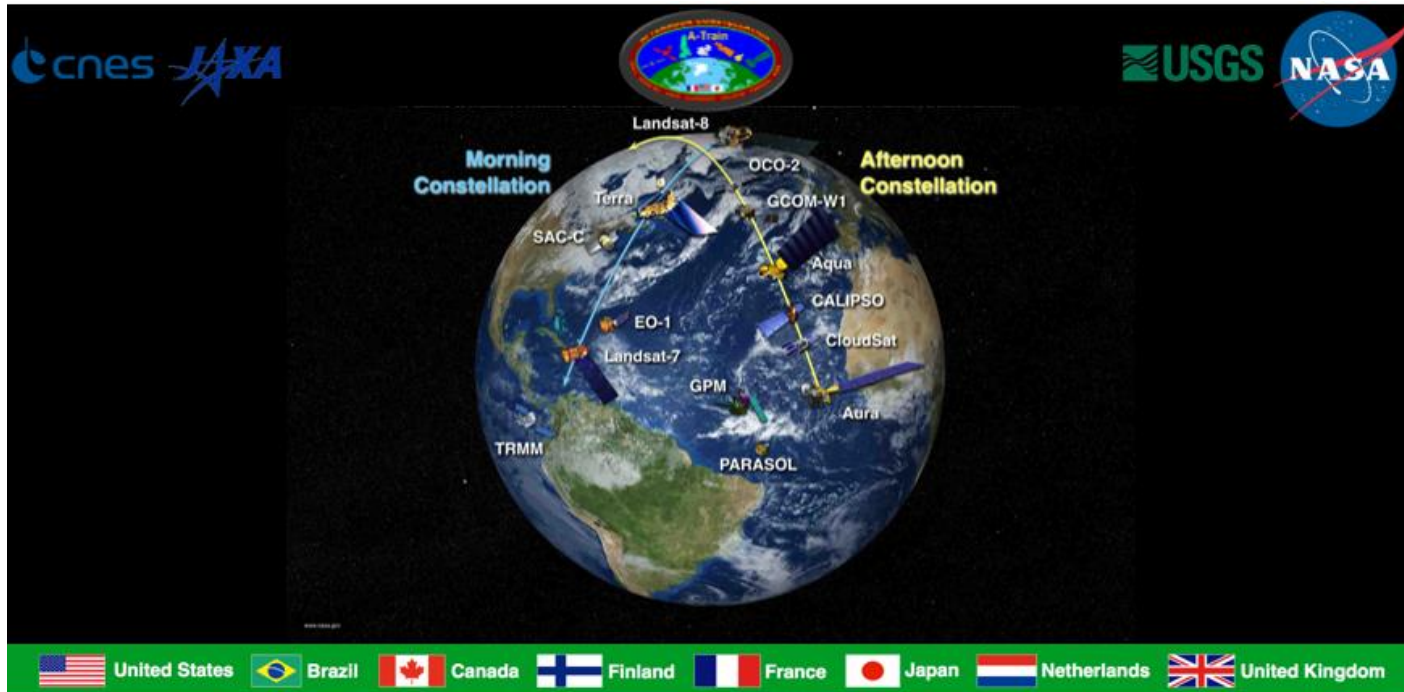
Inclination/MLT Maintenance (Fall 2015)



- **EOS Flight Dynamics has analyzed and updated the nominal inclination schedule that ensures Aqua's mean local time of the ascending node (MLTAN) remains within the current target range.**
 - The current target MLTAN range for Aqua is 13:35:45 +/- 45 sec.
 - Aqua's current mission MLTAN requirements are {13:30:00 - 13:45:00}
 - Aqua's performance from the 2015 inclination series was 1.29% COLD
- **Proposed long-term inclination adjust plan is predicted to keep Aqua within the target MLTAN range.**
 - Nominal case schedules Aqua inclination maneuvers that are not on weeks starting with Easter. The maneuvers are not centered around the ideal dates.
- **Will re-visit/re-validate the long-term plan after each series of annual inclination adjust maneuvers.**
- **See EOS Flight Dynamics Presentation for long-term plan.**



Inclination/MLT Maintenance (Long-Term Plan)



International Earth Science Constellation

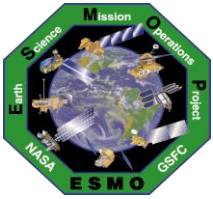
Mission Operations Working Group

April 13-15, 2016

Aqua Spring 2016 IAM Campaign and No-Slew DMU Results

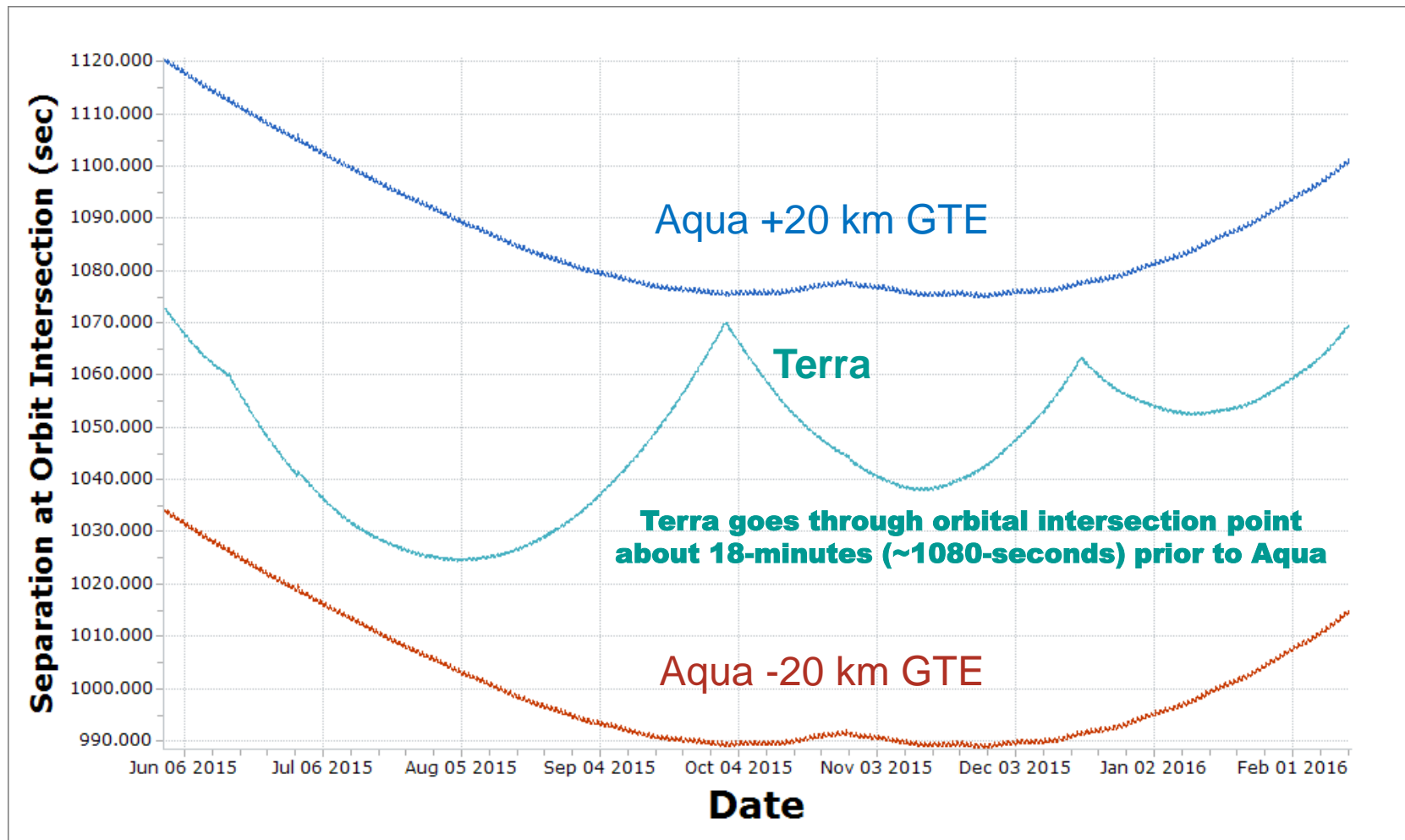
Avery C. Ruël and Tiffany Heyd

EOS FDS, esmo-eos-fds@lists.nasa.gov, +1.301.416.5050



Terra to Aqua Phasing

(as of Feb 16, 2016)





Questions