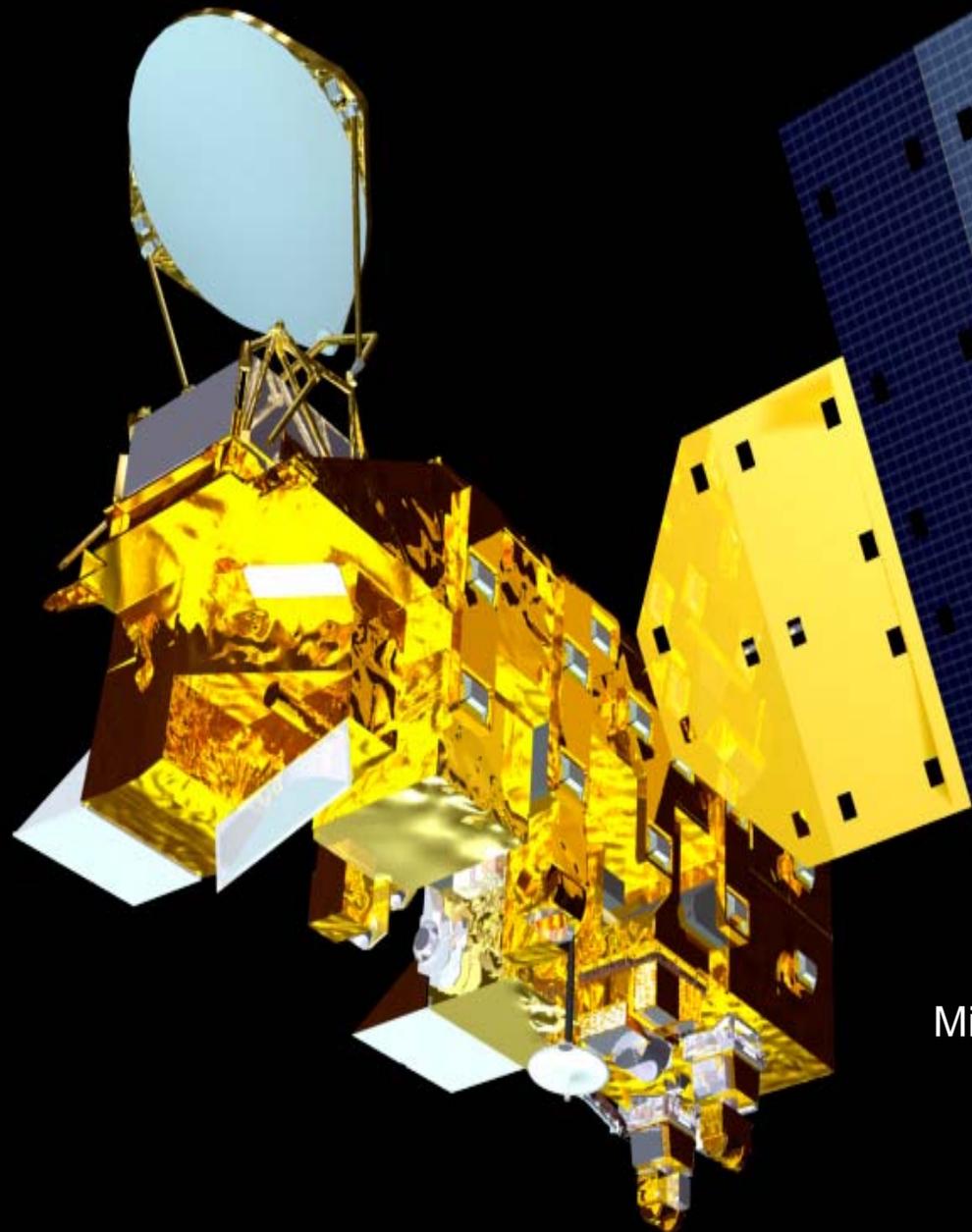


EOS Aqua



**Mission Status
at
Earth Science
Constellation
MOWG Meeting
@ GSFC**

June 2, 2015

Bill Guit

EOS Aqua and Aura Mission Director
Mission Validations and Operations Branch

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William.J.Guit@nasa.gov



Topics



- **Mission Summary**
- **Spacecraft Subsystems Summary**
- **Recent & Planned Activities – No Yaw Slew Maneuvers**
- **Inclination Adjust Maneuvers**
 - **Spring 2016 Calendar (DRAFT)**
 - **2015 Results & Long-Term Plan (in EOS FD 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 October 2014 Meeting at LaRC)



- **05/04/02: Launch**
 - 6-Year Design Life
- **12/02/08: End of Prime Mission Review**
- **07/10/13: 2013 Mission Extension Senior Review Proposal Panel Report**
 - #1 Ranked Earth Science Mission
 - Mission extension through FY17
- **07/22/13: Submitted Phase F Study**
- **05/04/14: Aqua 12-Year Anniversary**
- **01/21/15: FOT Annual Review #8**
- **03/03/15: Senior Review Proposal #5**
 - Reliability Estimates thru 2022
 - Consumables through 2021
- **04/29/15: SRP HQ presentations**

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 October 2014 MOWG at LaRC 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*
 - *ARE-6C (3/1/13) – post-anomaly investigation indicated 10/20/11 also*
 - » *Has been observed to intermittently drop-out and re-connect numerous times (last 2/10/15)*
 - *Previous ARE Anomalies: ARE-1C (11/8/10) & ARE-3A (2/14/12)*
 - » *Estimated that Aqua has lost 10 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**

4/30/2015



Recent Activities

(October 2014 – May 2015)



- **25 CARA High Interest Orbital Debris Events (October 2014 – May 2015)**
 - 9 that required significant action (Tier 3 + Tier 4) plus 8 additional Tier 2 HIEs
 - 11 RMM/DAMs PLANNED – 2 APPROVED/LOADED/WAIVED-OFF – 2 EXECUTED
 - 4+ Potential High Interest Events (PHIEs – Tier 0) required monitoring and/or planning
 - CARA Tier 3 HIE on 12/5 counted as ESMO Tier 4 (DAM)
 - » High-risk (1:794) then dropped off, returned to high-risk (1:327), 12/3 DMUM considered a DAM, secondary about half the size of Aqua, risk drops some, FOT executes DAM on 12/3
- **No Instrument anomalies – 1 minor ongoing spacecraft bus anomaly**
 - **10/14/2014: ARE-6C Power Drop Anomaly (#6)**
 - » Intermittently drops out and recovers – no impact to operations – last occurred on 2/10/2015
- **Spacecraft Delta-V Maneuvers: 9 Routine DMUMs, 5 IAMs and 2 DAMs**
 - **9 Routine DMUMs: 8 without yaw slews, one with a yaw slew (10/8/2014)**
 - » 2014: 10/8, 10/21 (DAM), 11/12, 12/3 (DAM), 12/17 (HAM), 1/7, 2/4, 2/26 (QDAM Test) and 5/dd (#97)
 - **2 Debris Avoidance Related Maneuvers without yaw slews**
 - » 2014: 10/21 (#9) and 12/3 (#10)
 - **5 Inclination Adjust Maneuvers:**
 - » 2015: 3/18 (#43), 3/25 (#44), 4/1 (#45), 4/15 (#46) and 4/22 (#47)
- **8 Instrument Calibration Maneuvers (Monthly MODIS Lunar Calibration)**
- **ESMO Maneuver Planning Process Review (Final Report sent 4/20/2015)**



Planned Activities



- **June 2015: Drag Make Up Maneuver (DMUM) # 98**
- **Fall 2015: Earth Science Constellation(ESC)/A-Train MOWG**
 - Update propellant budget, decommissioning analysis, reliability predictions,...
- **January 2016: Flight Operations Annual Review (#9)**
- **Spring 2016: Afternoon Constellation Science Meeting and ESC MOWG**
- **Spring 2016: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)**
 - 4/20/2016 (#48), 4/27/2016 (#49), 5/11/2016 (#50) & 5/18/2016 (#51)
- **May 2016: 2nd Annual CNES Conjunction Assessment Workshop (?)**
- **Mid-to-Long-Term Plans**
 - Routine Operations
- **Continue to improve Debris Avoidance Maneuver (DAM) responsiveness**
 - Additional details in John Nidhiry's Quick DAM (QDAM) presentation



New Quick DAM (QDAM) Operations Concept



In response to the constantly increasing number of predicted close approaches with orbital debris and operational satellites (High Interest Events – HIEs – see slide 18)

The EOS Flight Operations Team (FOT) has developed new ground system capabilities, operational procedures and products, to safely plan and execute Debris Avoidance Maneuvers (DAMs) in a significantly reduced amount of time (hours vs. days)

The new and improved procedures and products have....

- Eliminated the current critical path for instrument and communications subsystem commanding in the daily stored command load**
- Required less personnel and man-hours for preparation**
- Required fewer systems for preparation**
- Required generation of fewer products**
- Allows greater flexibility with burn duration and timing**



DRAFT Spring 2016 Inclination Adjust Plan



Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
27 EASTER	28	29	30	31	1 April	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20 Aqua IAM #48	21 Aura IAM #45	22	23
24	25	26	27 Aqua IAM #49	28 Aura IAM #46	29	30
1 May	2	3	4 Spring Break	5 Spring Break	6	7
8	9	10	11 Aqua IAM #50	12 Aura IAM #47	13	14
15	16	17	18 Aqua IAM #51	19 Aura IAM #48	20	21
22	23	24	25 Aqua Backup	26 Aura Backup	27	28



Propellant Usage

(Updated September 2014)



- **Initial Aqua lifetime fuel analysis in 2006**
- **Detailed Aqua & Aura lifetime analysis in 2008**
 - Presented to MOWG and at Aqua End of Prime Mission Review in December 2008
- **Initial Aqua Decommissioning Plan was delivered in September 2012**
 - Updated Lifetime Estimates
- **Updated August 29, 2013**
 - Updated propellant trends for IAMs & DMUMs
 - Updated definitive fuel usage
 - Updated predicted solar flux levels
 - 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)
- **Updated September 30, 2014**
 - Updated propellant trends for IAMs & DMUMs
 - Updated definitive fuel usage
 - Updated predicted solar flux levels
- **Annual updates provided each September**
 - **Final will be produced 60 days before start of decommissioning**



Flight Dynamics Support Services
FDSS-1012-004
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



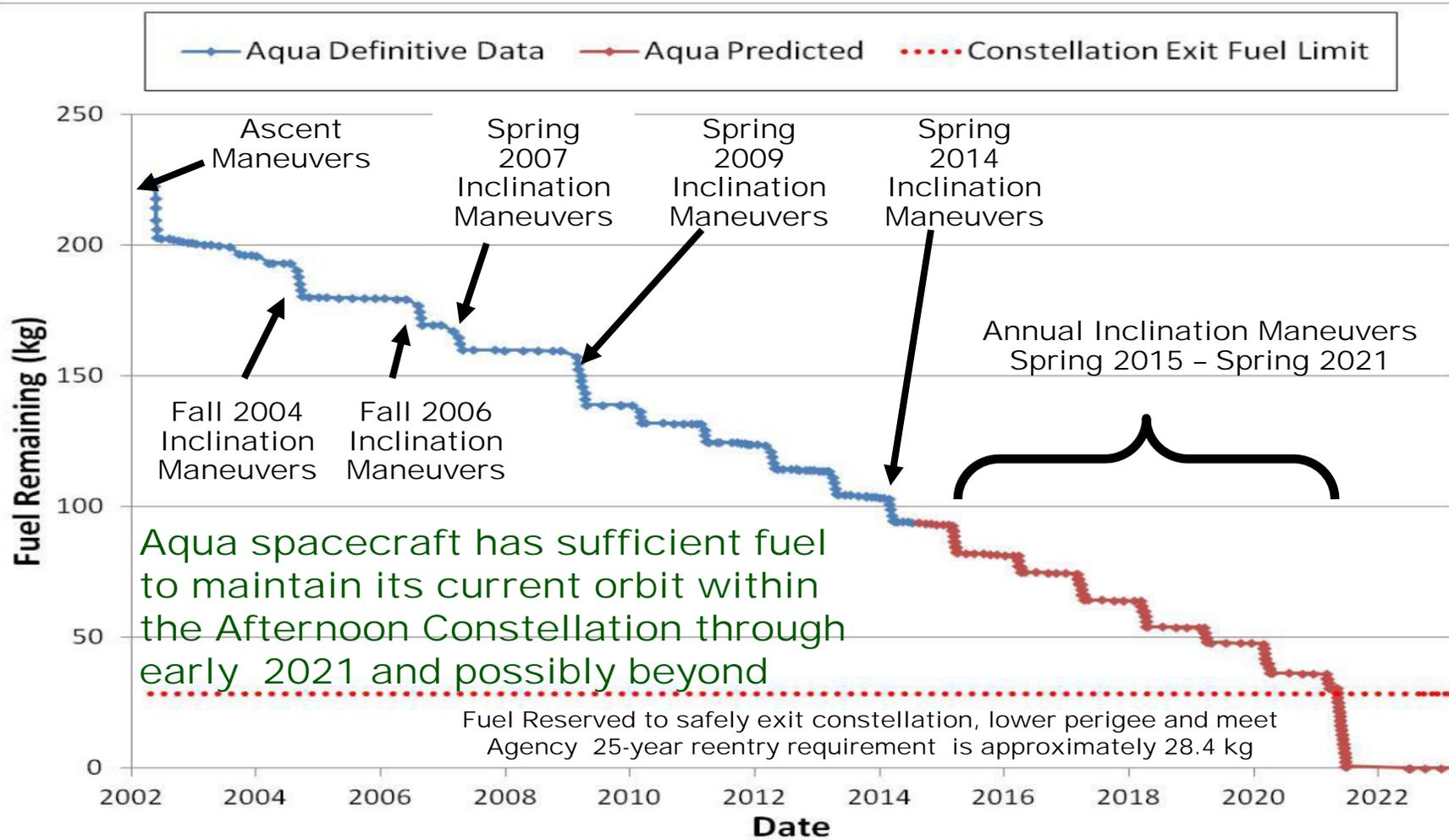
Remaining Fuel Estimate (September 2014)



- **Long-term orbit simulations were run for Aqua through 2021**
 - 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 its 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 at least 2021 and possibly beyond**
- **Analyses are updated annually by EOS Flight Dynamics Team after each series of inclination adjust maneuvers**



Fuel Usage: Actual & Predicted (September 2014)





Debris Assessment Software

(September 2014)



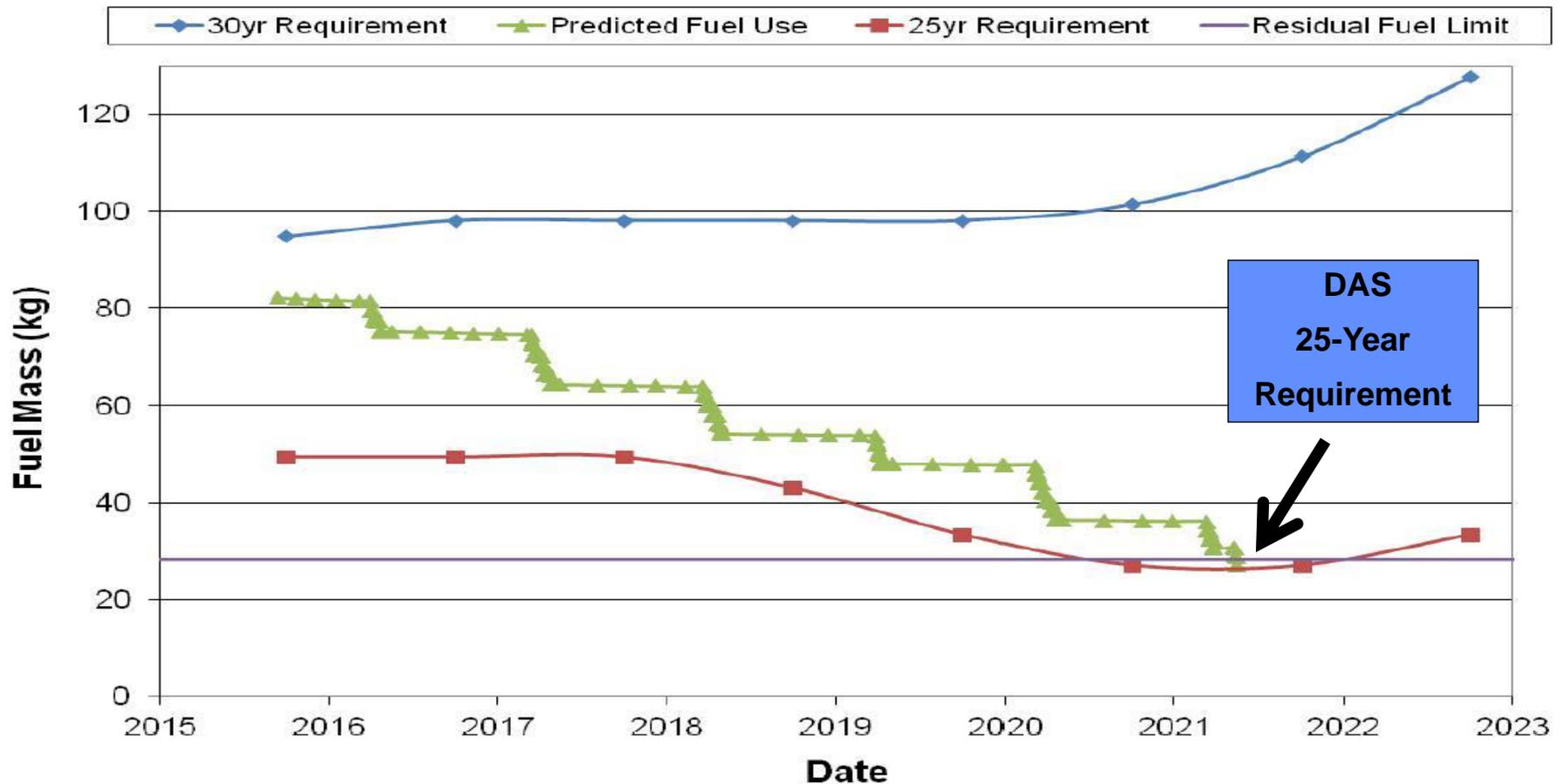
- **The Debris Assessment Software (DAS) was created by the Orbital Debris Office in Johnson Space Center and is the Agency standard for end of mission life analyses and lifetime estimations**
 - Current Version 2.0.2
- **DAS requires several inputs from a user describing a spacecraft's mission:**
 - 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**



Aqua DAS End of Life Predictions (September 2014)



Aqua Required Fuel Nominal Solar Flux Predictions and Operational Reentry Area

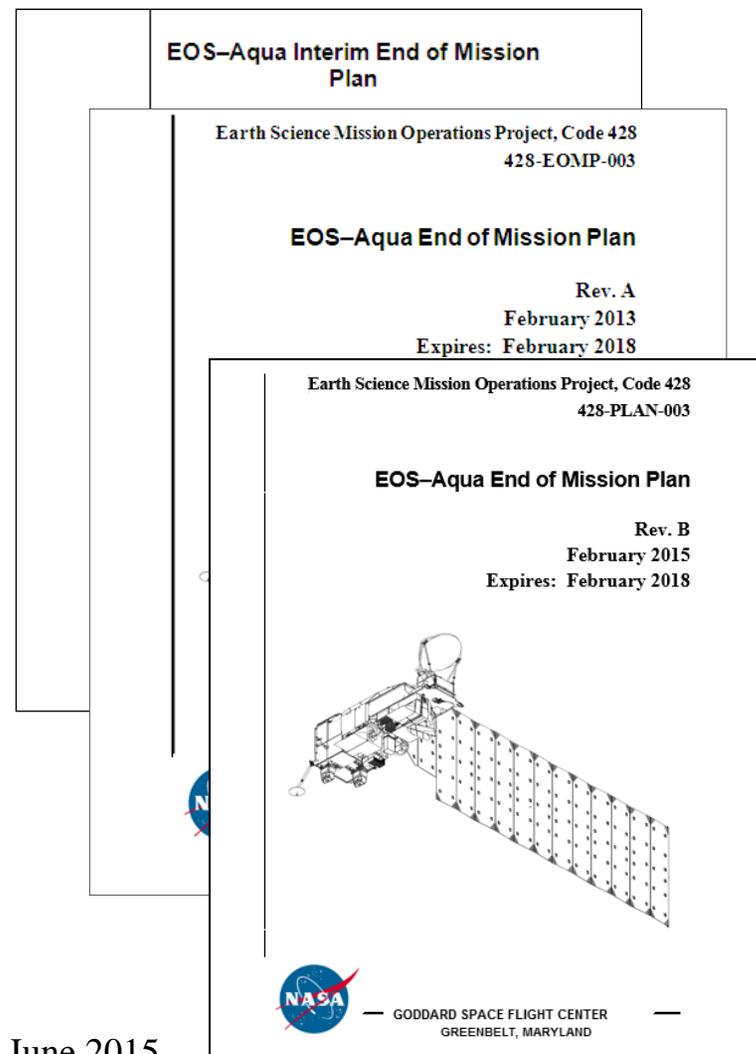




Changes since last ESC MOWG Aqua End of Mission Plan



- Initial draft February 2009
- Produced the first “Interim” End of Mission Plan (EoMP) in May 2011
 - Approved by NASA HQ July 2011
- Produced EoMP (Rev A): February 2013
 - Updated Lifetime Estimates (09/2012)
 - Added Small Object Collision Assessment
- Produced EoMP 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**





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
 - » 03/11/2013: Meeting with JAXA/MELCO Team in Tokyo
 - » 09/04/2013: Meeting with JAXA/MELCO Team in Oxnard, CA (No Changes)
 - » 09/23/2014: Meeting with JAXA/MELCO Team in Huntsville, AL (No Changes)
- **Data Capture/L0 Processing Status – GREEN**
 - **SSR Data Capture to 05/31/2015: 99.97843725+%**
- **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: Delivery 2/2/2015, Testing 2/16 – 6/19, ORR 6/24/2015**



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 **97** DMUMs have been performed
 - Variation in performance from -9.3% (cold) to +9.1% (hot)
 - **Last DMUM (#97) performed May 2015 – Next June 2014 (#98)**
- **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), **2015 (5)**



Aqua Conjunction Assessment High Interest Events



(10/1/14 – 5/31/15: 25 CARA HIEs – 21 Required Significant Action)

1. 10/01/2014: CA vs. 87568 on 10/04 at 00:28:13 GMT – Repeating CAs (21), DAMs planned for 10/3, CAM'd, waived-off (T3)
2. 10/16/2014: CA vs. 37125 on 10/19 at 20:08:48 GMT – Repeating CAs (7), short-notice (4-days), DAMs planned, self-mitigated (T3)
3. 10/20/2014: CA vs. 81180 on 10/21 at 04:18:27 GMT – Short-notice high-risk CA (Pc 6.88E-04), DAM planned and executed (T3?)
4. 11/13/2014: CA vs. 81429 on 11/17 at 08:08:20 GMT – Part of a cluster of 3 Aqua conjunctions (T2)
5. 11/13/2014: CA vs. 33909 on 11/17 at 22:54:21 GMT – Aqua cluster of CAs (T2)
6. 11/19/2014: CA vs. 22357 on 11/21 at 21:40:50 GMT – Planned DAMs, self-mitigated (T3)
7. 11/21/2014: CA vs. 35986 on 11/24 at 08:21:21 GMT – 2.8 days to TCA, Planned DAMs, non-actionable, Pc of 1:2500 (T3)
8. 11/21/2014: CA vs. 34624 on 11/24 at 13:45:18 GMT – 3.1 days to TCA, self-mitigated (T2)
9. 11/28/2014: CA vs. 04370 on 12/05 at 06:22:30 GMT – RED HIE (max Pc of 1 in 313), DAMs planned & Executed on 13/3 (T3?)
10. 12/08/2014: CA vs. 35026 on 12/14 at 17:04:25 GMT – RED HIE (max Pc of 1 in 641), self-mitigated, (T2)
11. 12/13/2014: CA vs. 40234 on 12/15 at 03:42:07 GMT – Short-notice, repeating CAs, part of a cluster of CAs (T2)
12. 12/13/2014: CA vs. 38839 on 12/15 at 14:18:56 GMT – Part of a cluster of conjunctions, self-mitigates, (T2)
13. 01/05/2015: CA vs. 35929 on 01/10 at 16:32:52 GMT – RED HIE, DAMs planned, self-mitigated (T3)
14. 01/16/2015: CA vs. 33967 on 01/20 at 07:16:19 GMT – CA followed, no action required (T2)
15. 01/22/2015: CA vs. 32226 on 01/24 at 15:01:54 GMT – Near co-planar low relative velocity CA, 3 HIE Briefings (T2)
16. 02/09/2015: CA vs. 37984 on 02/13 at 21:17:22 GMT – DAMs planned CAM'd, updated tracking, waived-off (T3)
17. 03/21/2015: CA vs. 87155 on 03/24 at 15:45:49 GMT – RED HIE, 7 CAs, DAMs sized, new tracking, Pc rolled-off (T?)
18. 03/23/2015: CA vs. 37925 on 03/28 at 07:54:28 GMT – PMCOC, CARA NO-GO for 3/24 IAM, new tracking (T3)
19. 04/01/2015: CA vs. 34020 on 04/05 at 00:31:19 GMT – DAMs planned, self-mitigated (T_)
20. 04/20/2015: CA vs. 19048 on 04/26 at 14:42:00 GMT – post-IAM potential conjunction of concern (T_)
21. 04/17/2015: CA vs. 35679 on 04/21 at 07:57:50 GMT – Began planning DAMs, self-mitigated (T_)

Aqua Summary:

**11 DAMs Planned, 2 DAMs Executed, 7 DAMs that self-mitigated,
2 DAMs that were approved and waived-off,
0 Routine maneuvers postponed/rescheduled**

4/30/2015 10:00 AM

ESC MOWG - June 2015

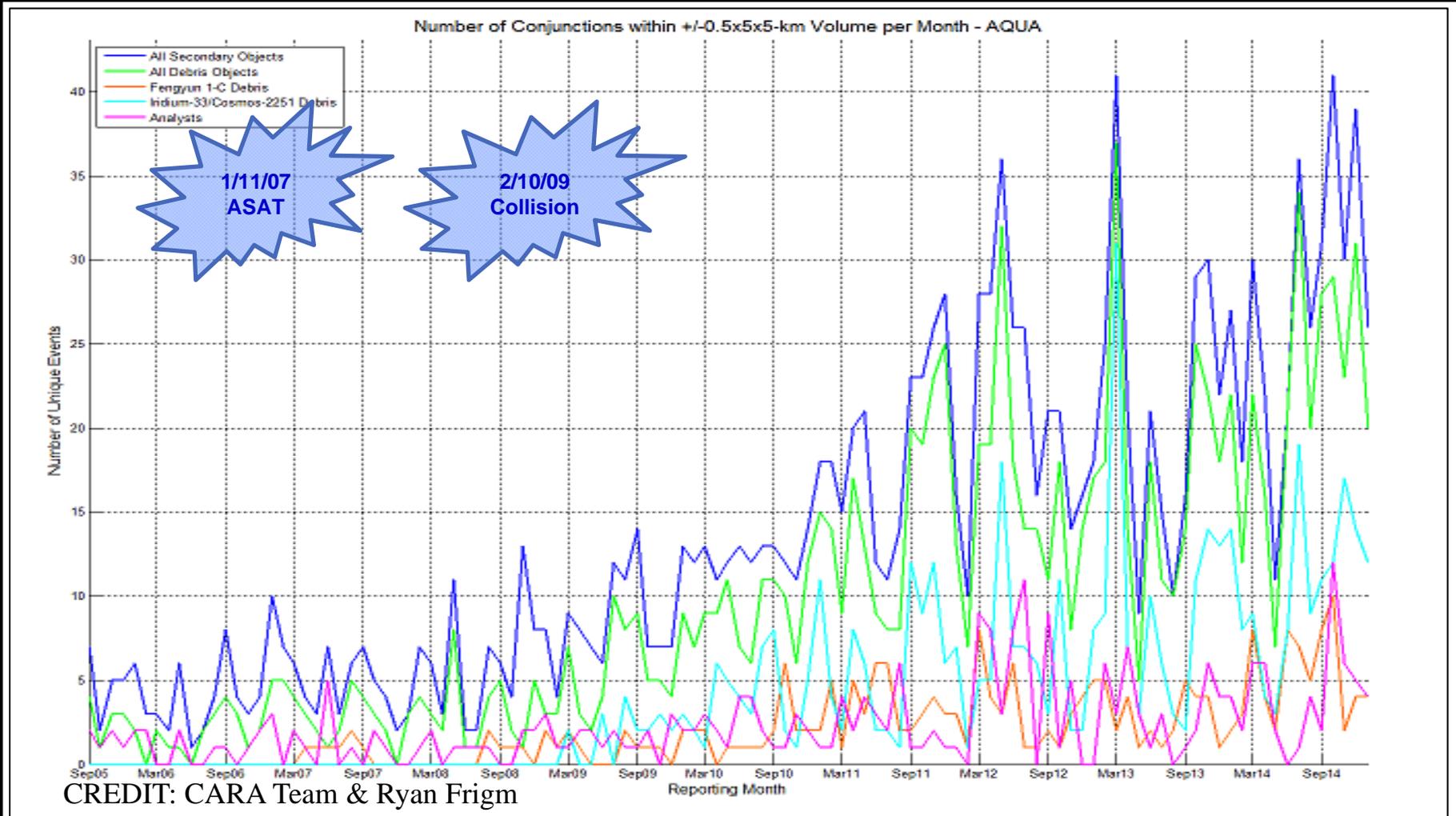
18



Aqua Conjunction Assessment Statistics



(September 2005 thru December 2014)



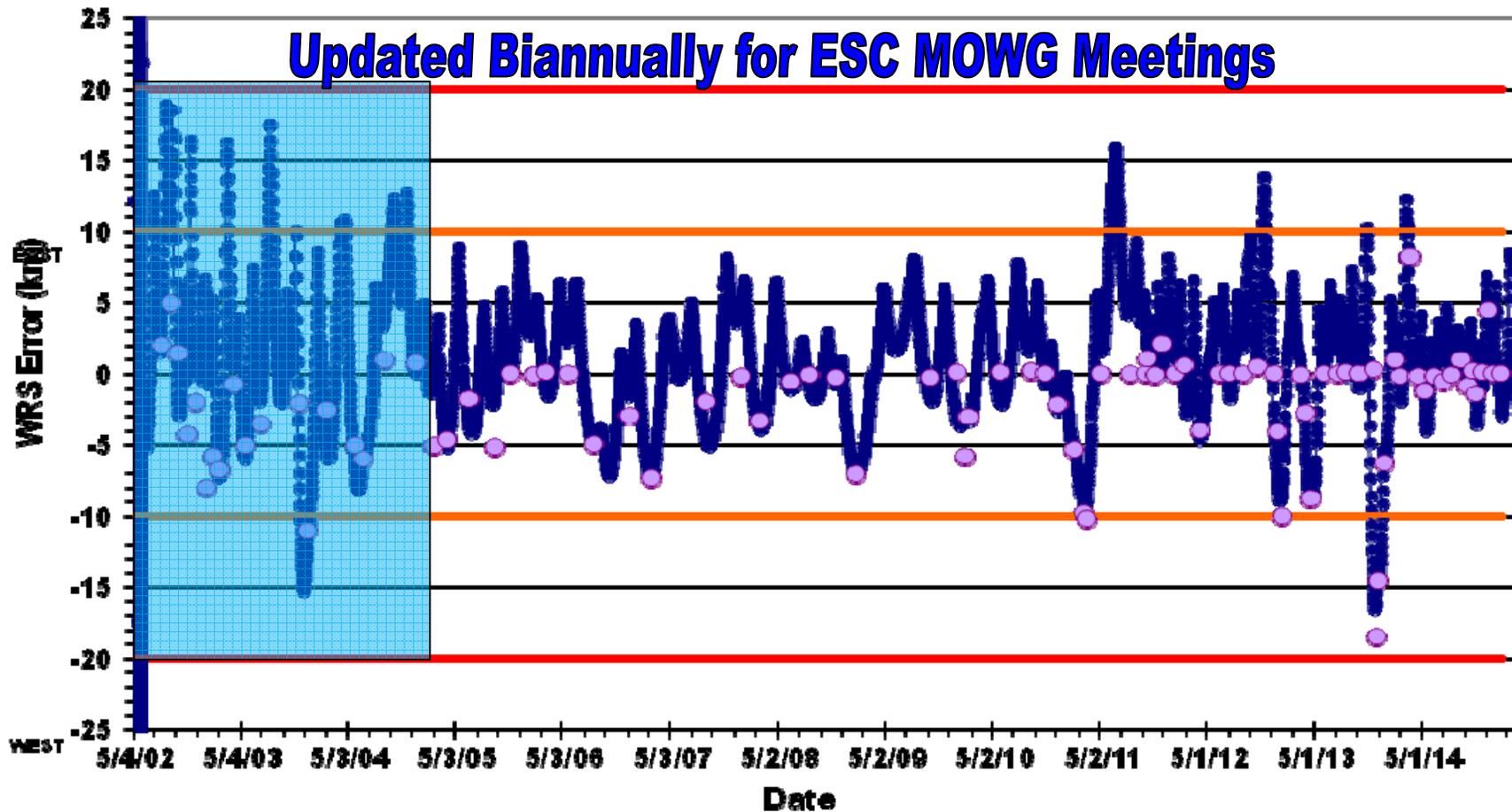


WRS Ground Track Error (GTE)

(as of March 2, 2015)



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



4/30/2015 10:00 AM

ESC MOWG - June 2015

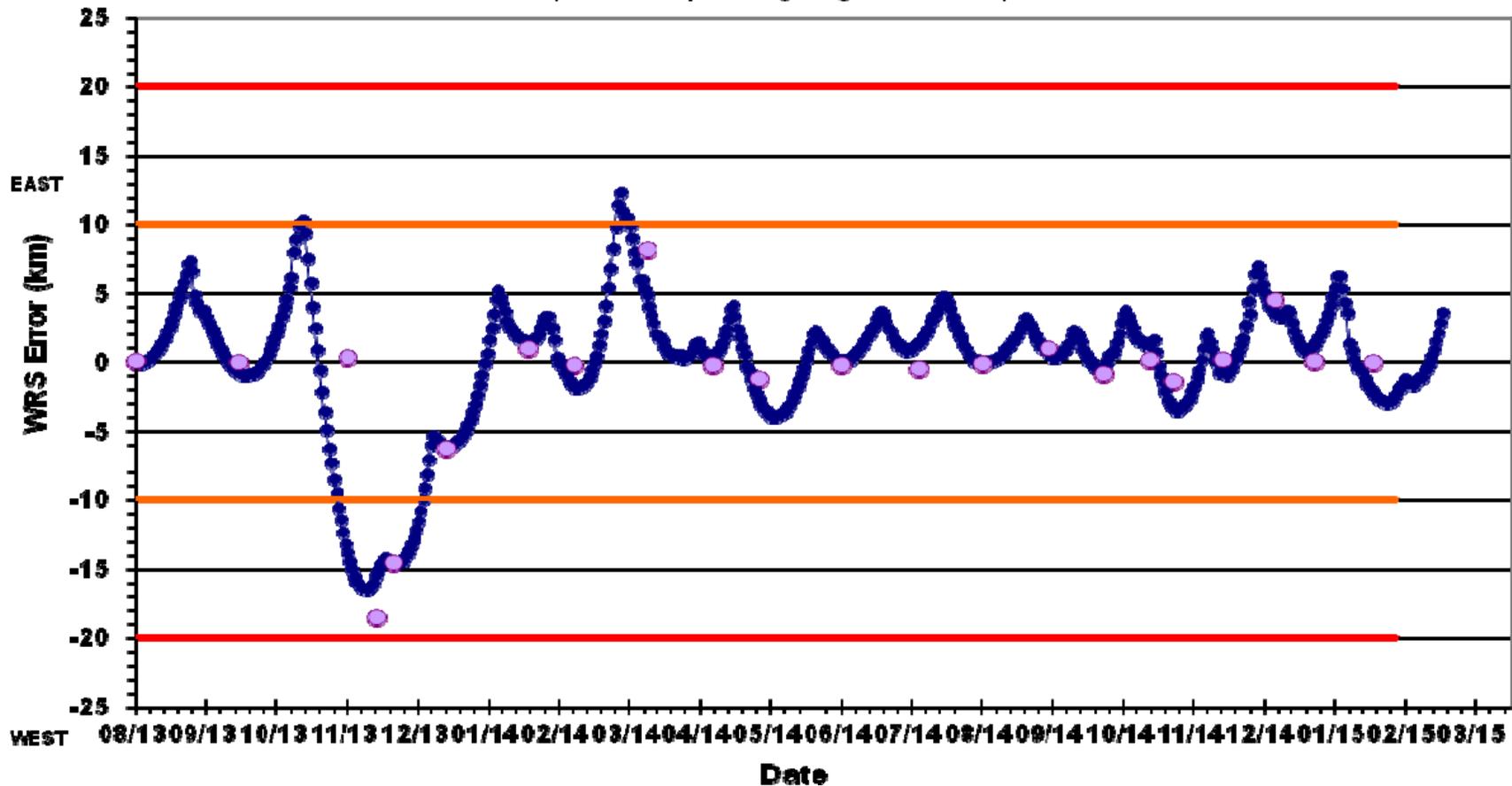


WRS Ground Track Error (GTE)

(Last 18 months or so – DMUM #96 CAM – 02/25/2015)



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

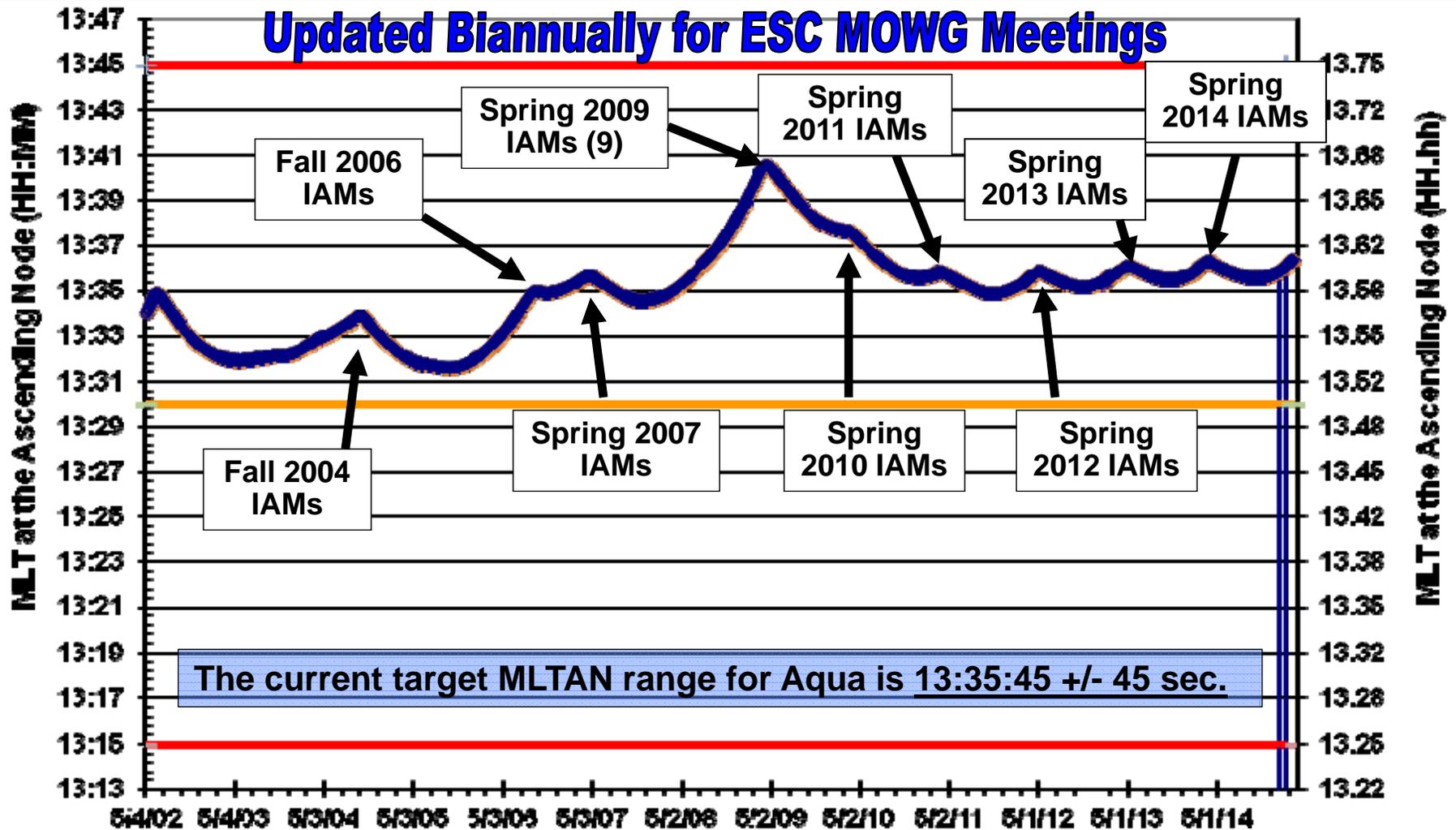




Aqua averaged MLT @ Ascending Node (as of March 2, 2015)

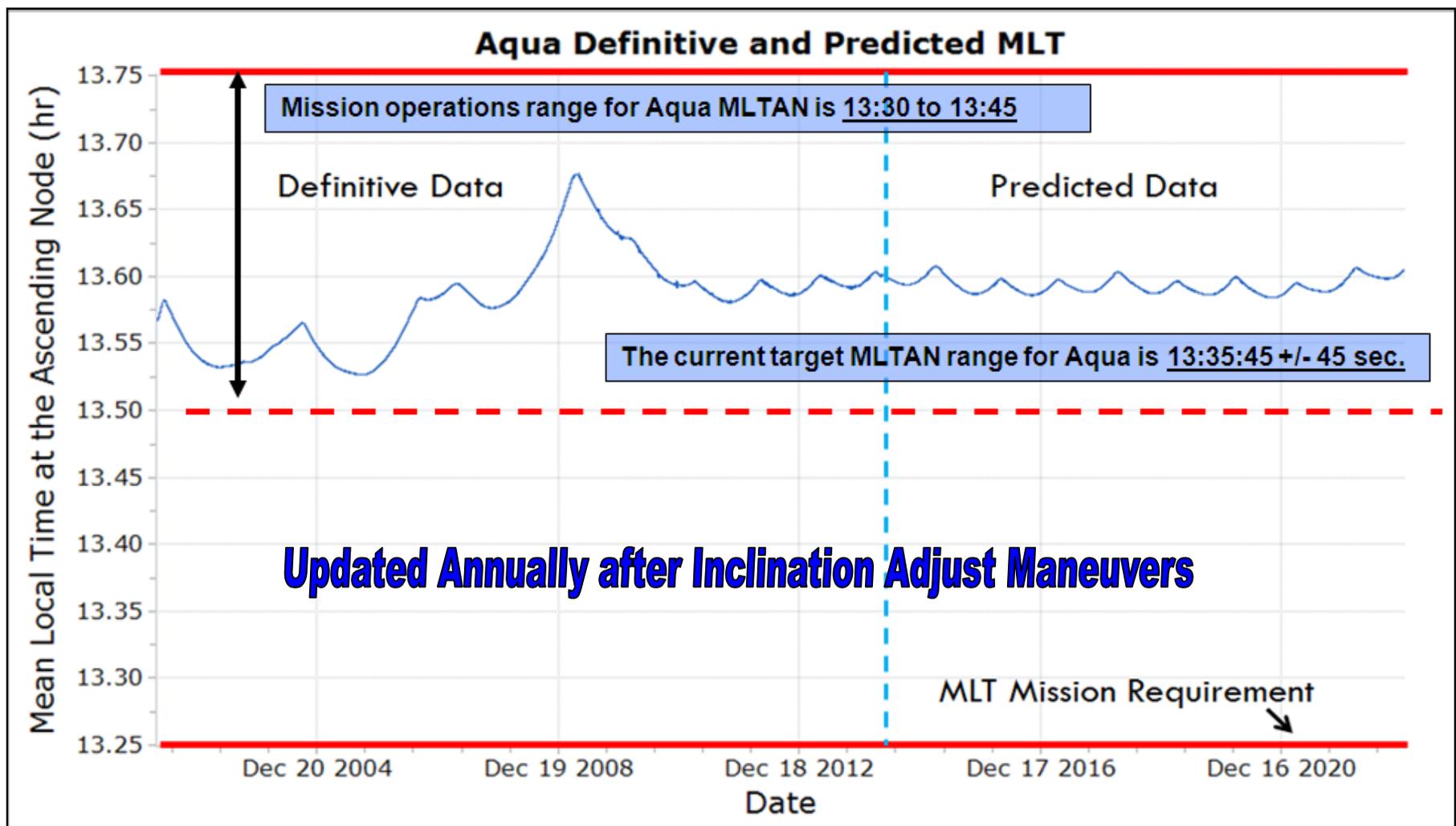


Updated Biannually for ESC MOWG Meetings





Aqua MLT @ Ascending Node (as of May 1, 2014)





Inclination/MLT Maintenance

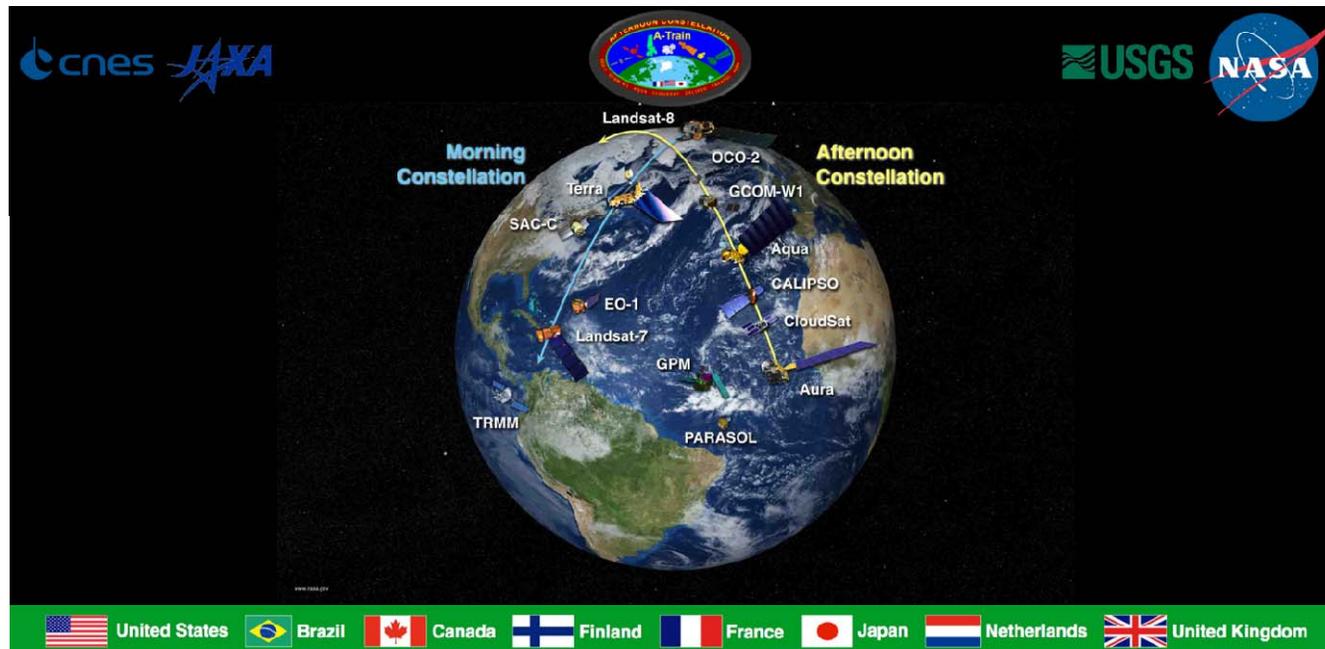
(April 23, 2015)



- **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
October 15-17, 2014**

Aqua and Aura Plans for Spring 2015 IAM Campaign

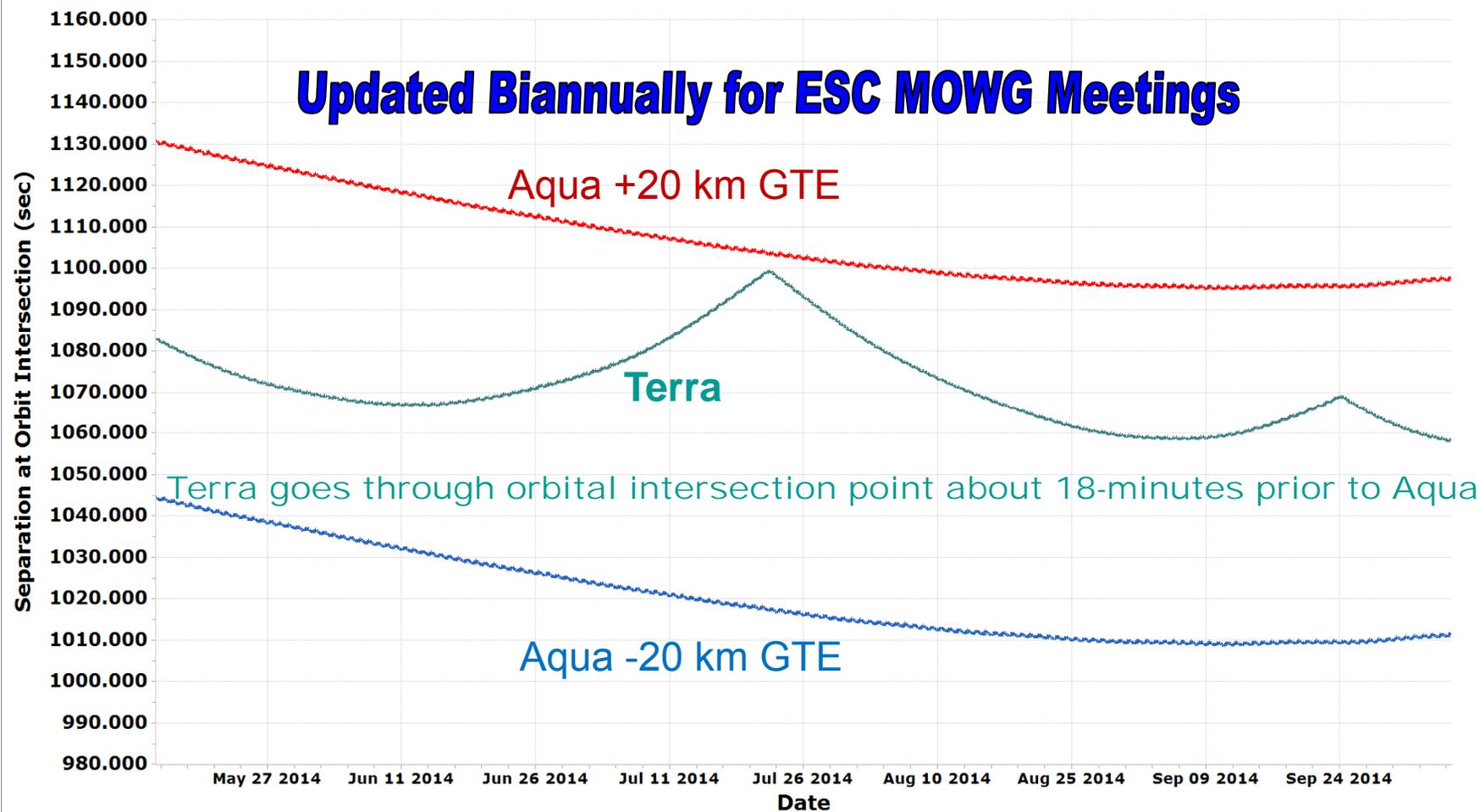
Ryan Moore & Brandon Holladay

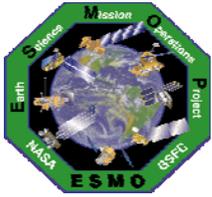
EOS FDS, eosfds@ai-solutions.com, +1.301.416.5050



Terra to Aqua Phasing

(as of October 7, 2014)





Questions