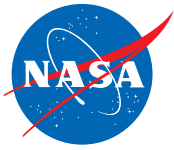


Aqua Status, Activities in the Past 12 Months, and Future Plans

**Claire L. Parkinson/Aqua Project Scientist
NASA Goddard Space Flight Center**

Presentation at the NASA AIRS/Sounder Science Team Meeting,
Online, October 26, 2021



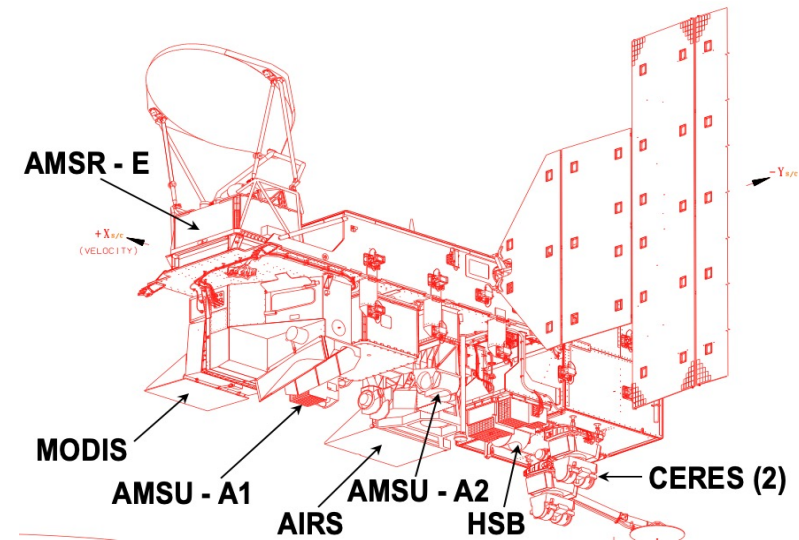
Instrument Status

Still operating (all provided by the U.S.)

- Atmospheric Infrared Sounder (AIRS)
 - Excellent health.
- Advanced Microwave Sounding Unit (AMSU)
 - Fair health (10 of 15 channels are performing well).
- Clouds and the Earth's Radiant Energy System (CERES; 2 copies)
 - Flight Model 3 (FM-3): Excellent health.
 - Flight Model 4 (FM-4): Good health (2 of 3 channels remain operational).
- Moderate Resolution Imaging Spectroradiometer (MODIS)
 - Excellent health.

No longer operating

- Humidity Sounder for Brazil (HSB)
 - Provided by Brazil's Instituto Nacional de Pesquisas Espaciais (INPE).
 - Not operating since February 2003.
- Advanced Microwave Scanning Radiometer for EOS (AMSR-E)
 - Provided by the Japan Aerospace Exploration Agency (JAXA).
 - Not operating since March 2016.

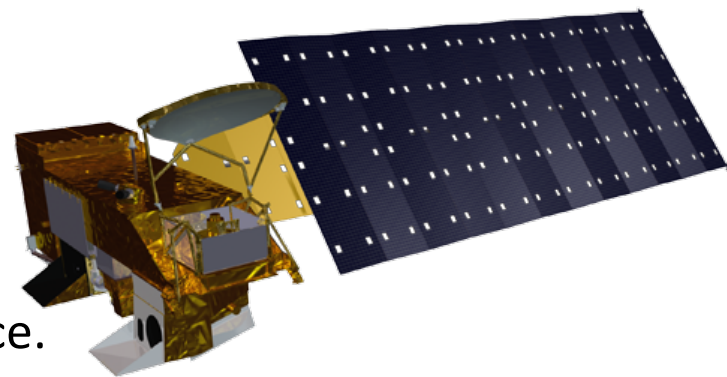




Status of the Spacecraft Bus, Solar Array, and Battery

• Aqua Bus

- Overall status: Excellent.
- All components remain on primary hardware.
- One of four thrusters has degraded performance.



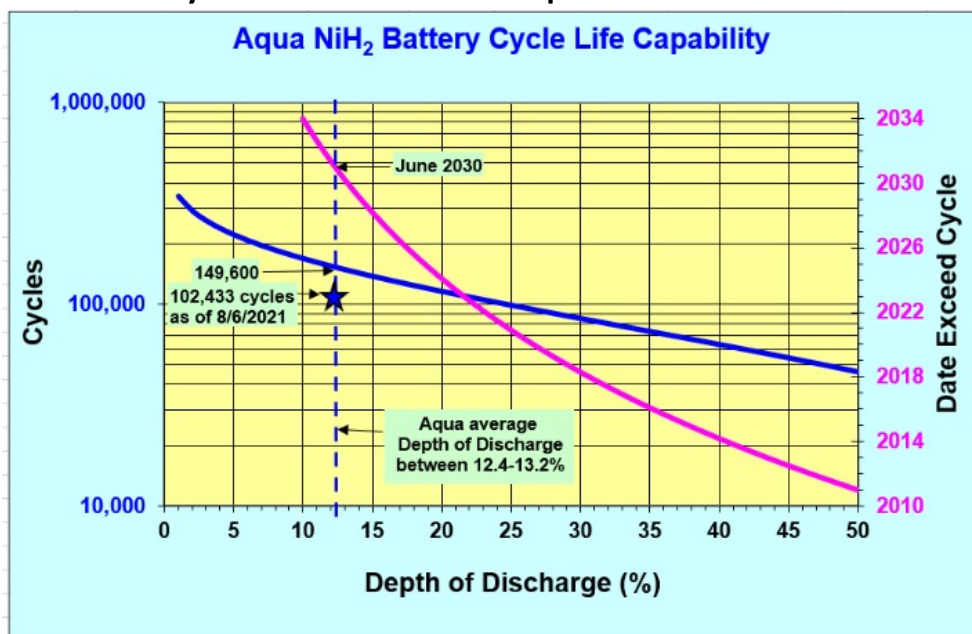
• Aqua Solar Array

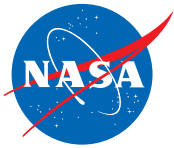
- 109 of the 132 strings of solar cells continue to operate.
- The solar array could likely operate at least until early 2028 if Aqua were to remain in its A-Train orbit; exiting the A-Train in early 2022 would likely bring the effective performance of the solar array to an end in September 2025.

• Aqua Battery

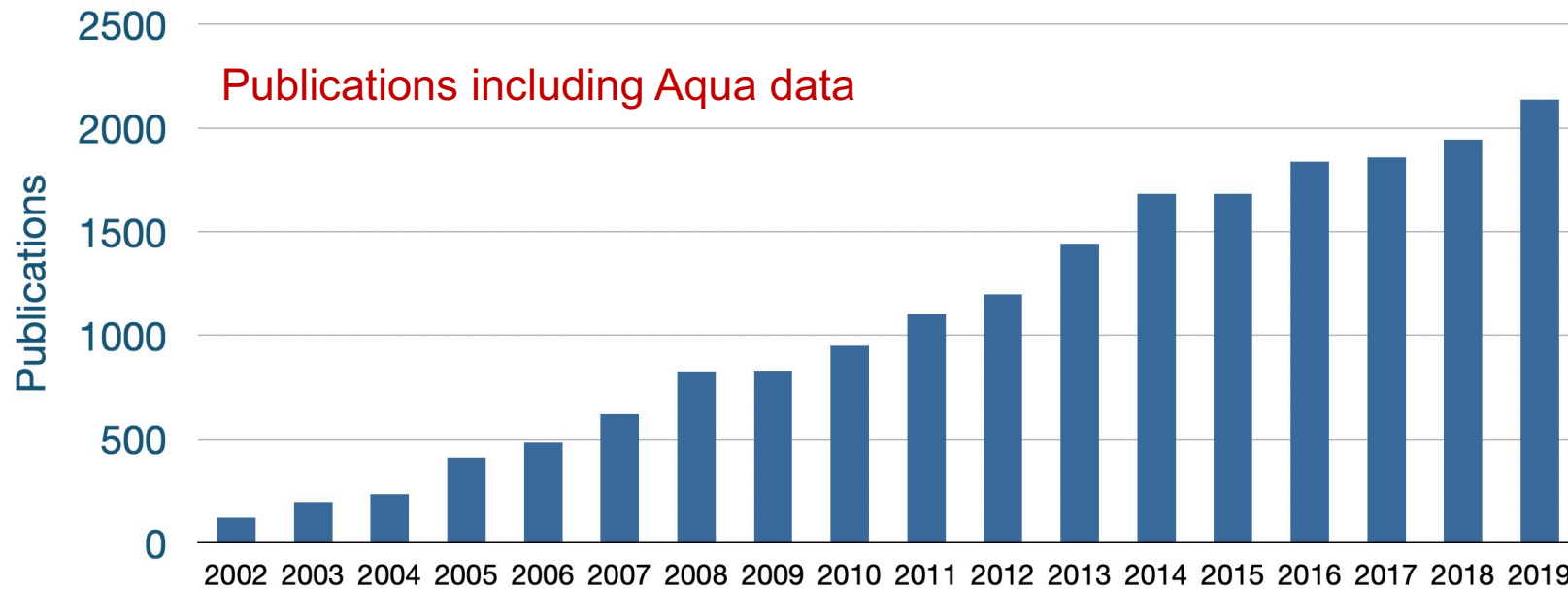
- All 24 cells of the main Aqua battery remain fully operational.
- The battery could potentially last over 149,000 Earth orbits, until mid-2030 and perhaps beyond.

(Aqua visualization by Marit Jentoft-Nilsen; plot based on data from Eagle Picher, the battery's manufacturer)

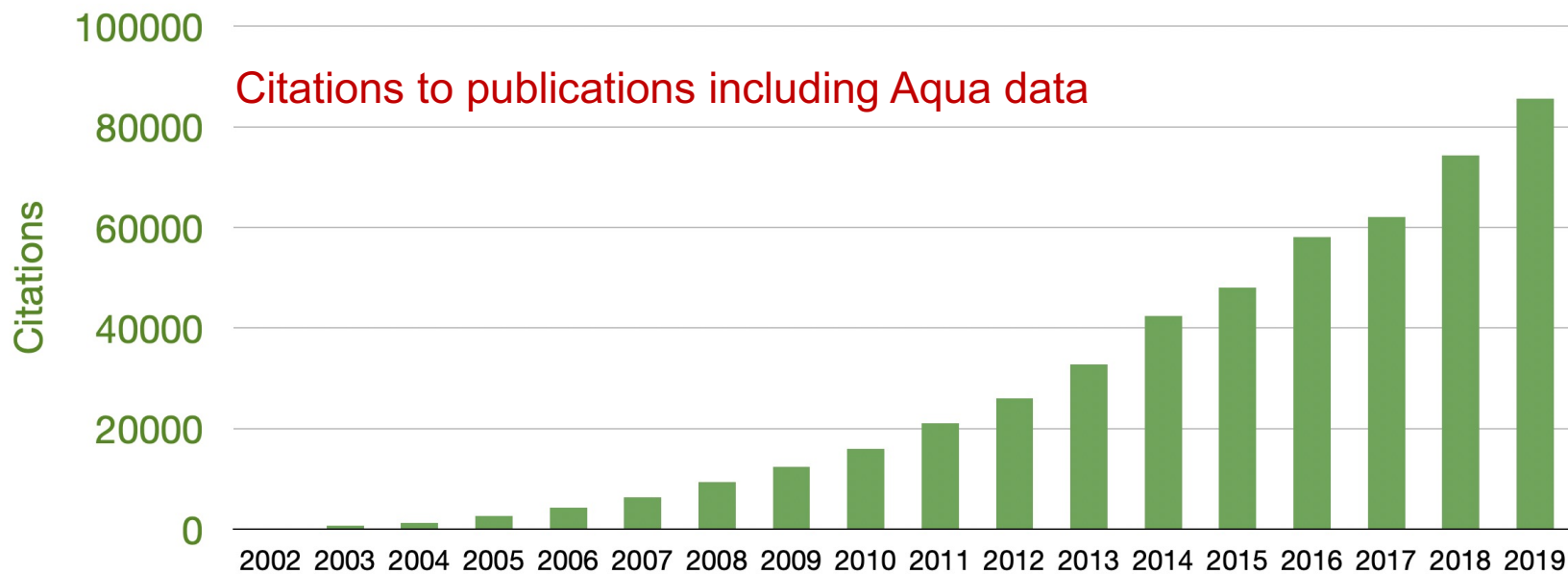




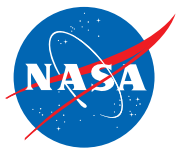
Aqua's Science Productivity (year by year)



Totals:
> 19,000

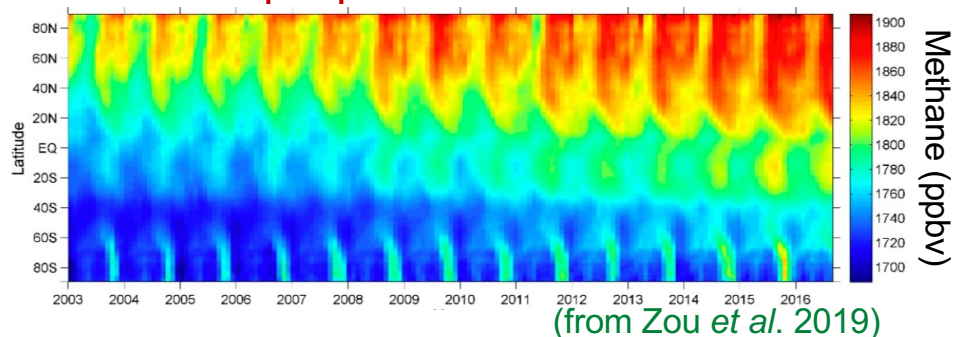


> 498,000

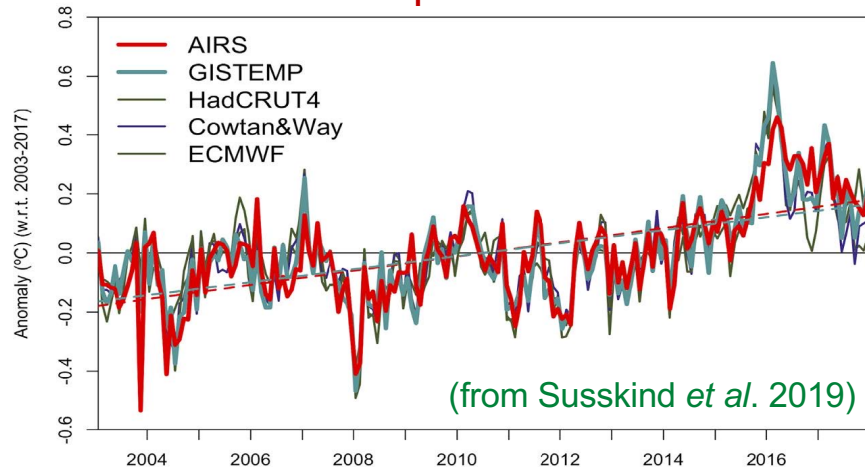


Sample Aqua Science

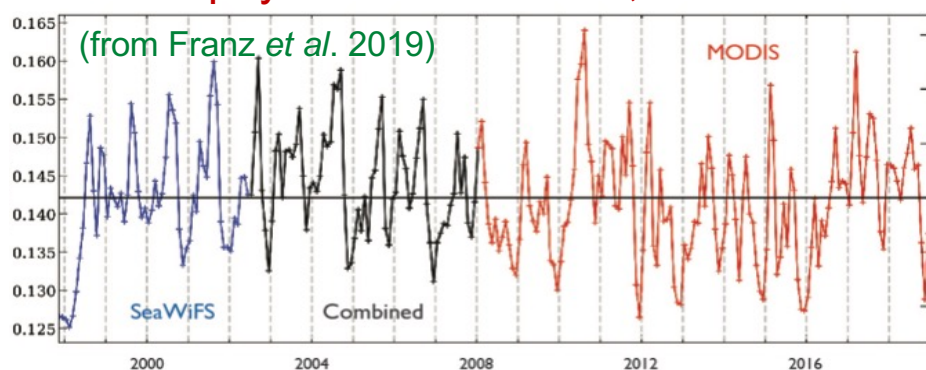
Zonal tropospheric methane from AIRS



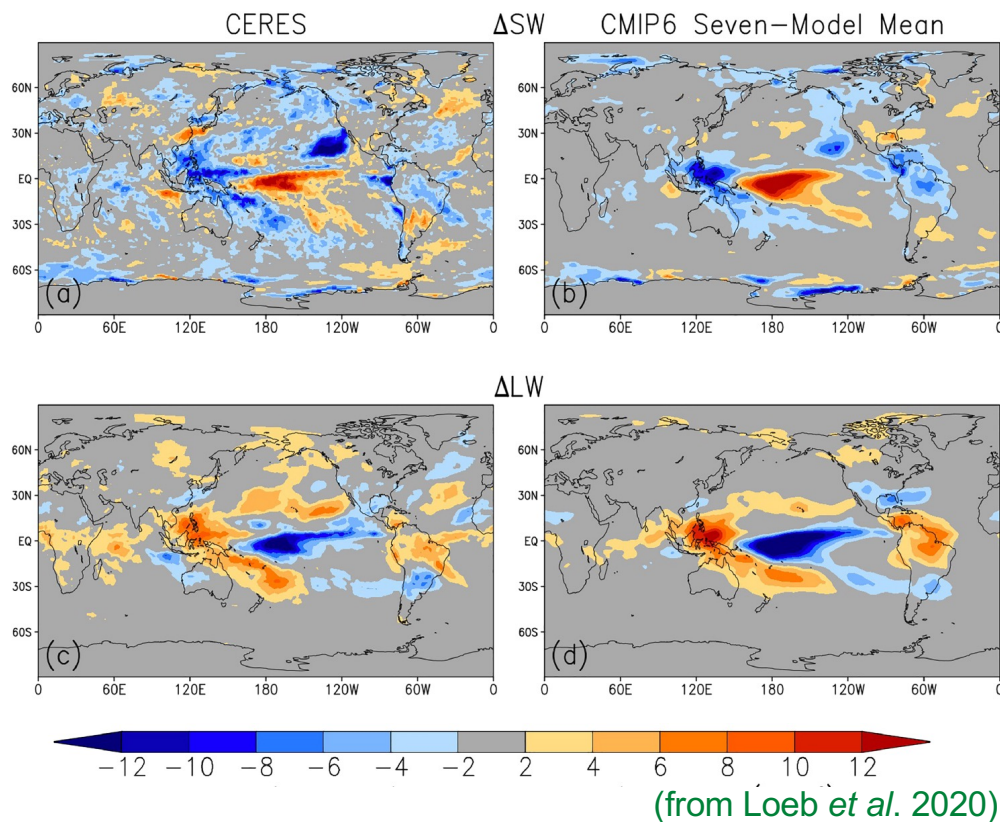
Global surface temperature from AIRS etc.



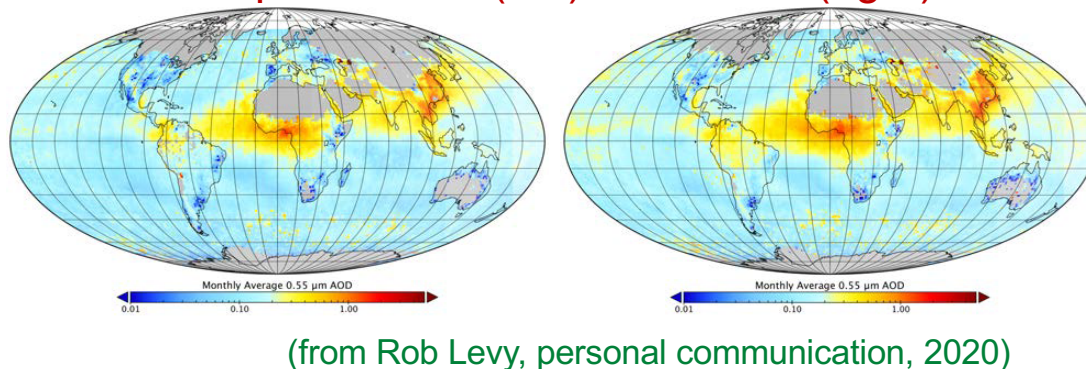
Chlorophyll-a concentration, 40°N – 40°S

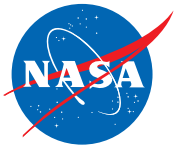


Reflected SW and outgoing LW fluxes (Wm⁻²) for 7/2014-6/2017 versus 7/2000-6/2014, from CERES (left) and models (right)



Aerosol optical depths, March 2015, from Aqua MODIS (left) and VIIRS (right)



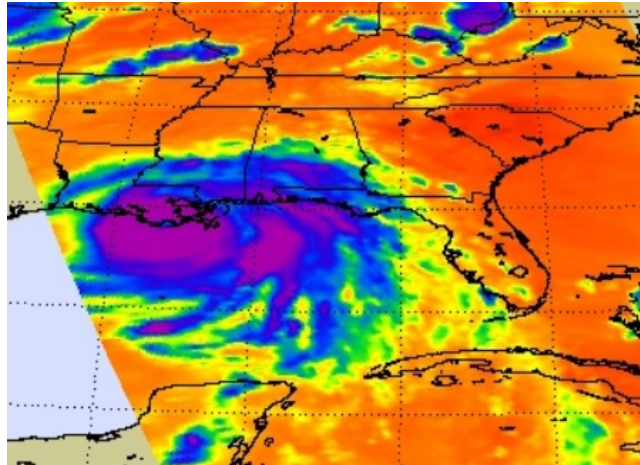


Sample Applied Uses of Aqua Data

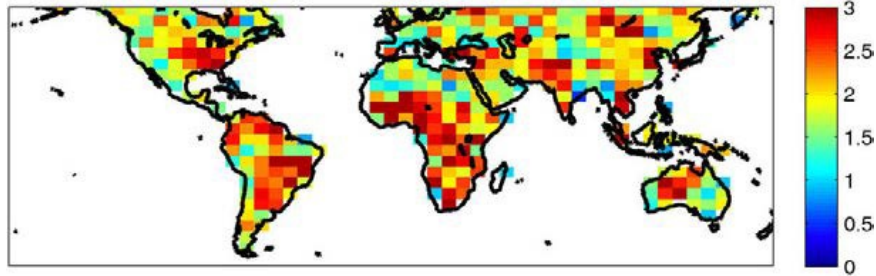
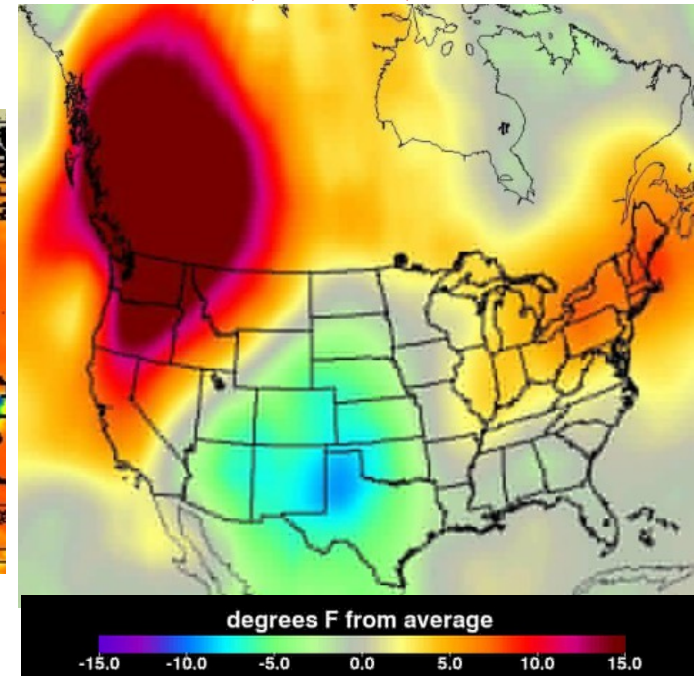
Fires in Russia, 8/8/21, from MODIS



Hurricane Ida, 8/29/21, from AIRS

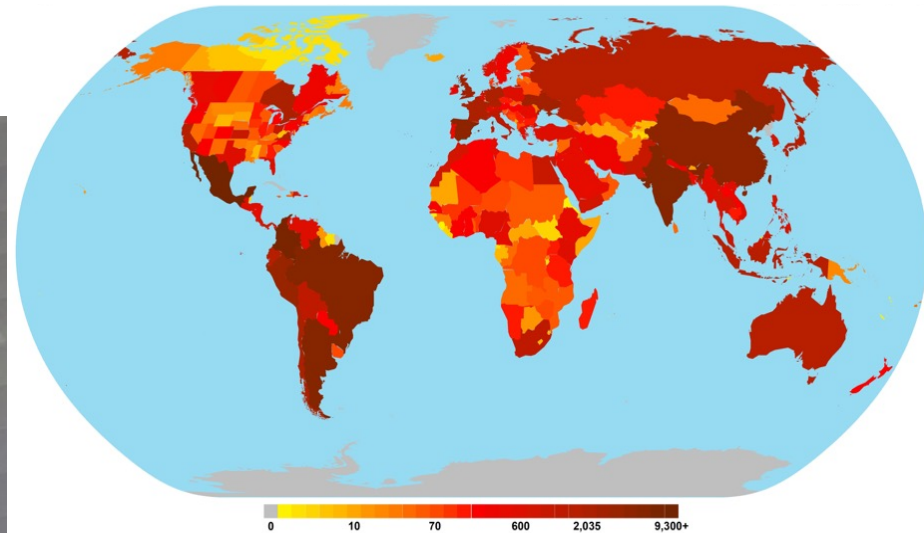


Heat wave over northwest U.S. and Canada, 6/30/21, from AIRS

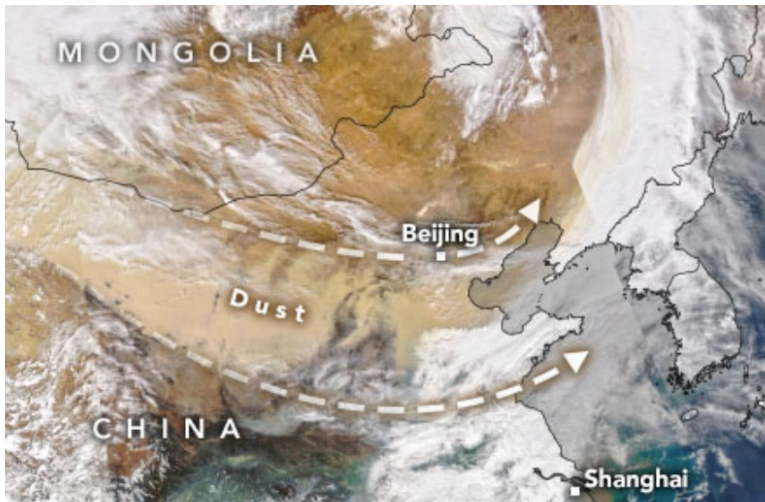


Improved mean lead time (in months) for early drought detection through incorporating AIRS relative humidity data

CERES FLASHFlux users, 5/16/18 - 11/30/19

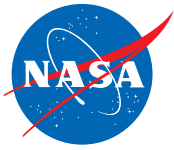


Dust storm in China, 3/15/21, from MODIS



Oil spill, 4/25/10, from MODIS





Report of the 2020 Senior Review Panel

- 140 pages, covering 13 missions.
- Very favorable toward Aqua.
 - “Excellent” ratings for each science category: Science Merit, Relevance, and Data Quality.
 - “Very High” utility rating.
 - Recommendation for the Over-guide budget.
 - Summary statement: **“The Senior Review Science Panel unanimously finds there is enormous potential benefit in continuing to receive Aqua data ... The Senior Review Panel finds in support of Aqua's extension with the over-guide budget for both FY 2021-2023 and FY 2024-2026.”**

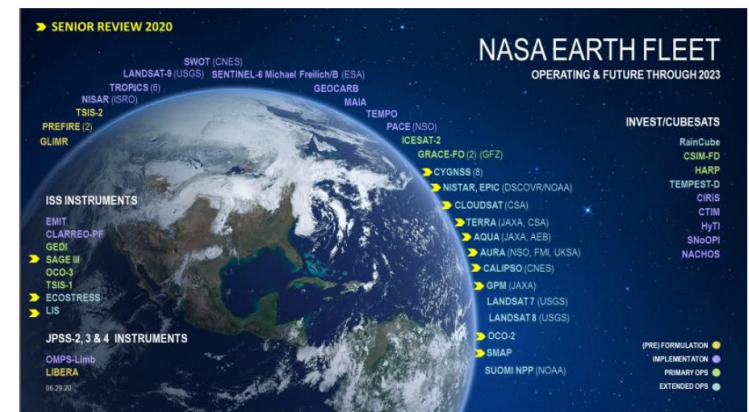
NASA Earth Science Senior Review 2020

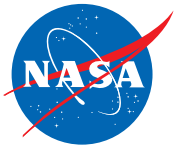
Submitted to:

Dr. Karen St. Germain
Director, Earth Science Division, Science Mission Directorate

Ana P. Barros (Chair), Rachel Albrecht, Linnea Avallone,
William H. Brune, Shu-Hua Chen, Anthony Didlake Jr, Qiang Fu, Geoffrey M.
Henebry, Brian K. Hornbuckle, Anna Michalak,
Stephen Nesbitt, Wenge Ni-Meister, Anita D. Rapp, and Jun Wang

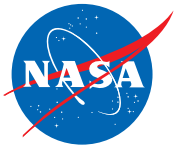
August 31, 2020






“Guidance Letter” from NASA HQ, received 10/21/20

- Praise for the Aqua mission
- Funding decisions
 - In-guide funding for FY21, with no FY21 over-guides for the algorithm maintenance efforts.
 - Over-guide funding for FY22 and FY23.
 - In-guide funding for FY24 and FY25, to be reconsidered through the 2023 Senior Review process.
- Actions Items
 - Update the *Phase F Plan*, for the final years of the mission, after data collection ends.
 - Continue to hold annual Mission Operations Reviews.
 - Provide a quantitative assessment of the impact (on data utility) of changes in mean local time (MLT) after Aqua exits the A-Train.
 - Hold a Users’ Workshop to communicate changes in the data sets and prepare users for the mission’s end of life.
 - Submit a 2023 Senior Review proposal.



2021 Aqua Phase F Plan

- Submitted March 24, 2021.
- Summarizes what needs to be done in the two years after data collection ends.
 - Update the End of Mission Plan and Decommissioning Plan
 - Perform final instrument calibrations and turn off the instruments.
 - Lower the spacecraft.
 - Deplete the remaining fuel.
 - Passivate the spacecraft.
 - Prepare the spacecraft Final Report.
 - Complete science team activities: Algorithm updates; Final calibrations; Data processing; Data documentation; Data archival; Science team meetings.
- Assumes, by instruction, the unrealistic date of 10/1/21 for when NASA HQ issues the directive to terminate the mission.



The cover page of the 'Aqua Phase F Close Out Plan' document. At the top right is a 3D rendering of the Aqua spacecraft. The title 'Aqua Phase F Close Out Plan' is prominently displayed in white text on a dark grey background. Below the title, it states 'Submitted to NASA Headquarters on March 24, 2021'. On the left side, there is a photograph of the Aqua spacecraft being mated to the International Space Station's External Stowage Platform. To the right of the photo is a list of key personnel and their roles. At the bottom left, a credit line reads '(Photo courtesy of Northrop Grumman/TRW)'.

**Aqua Phase F
Close Out Plan**

Submitted to NASA Headquarters on March 24, 2021

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

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

Mr. William J. Guit, Aqua Mission Director/ESMO
NASA Goddard Space Flight Center

Mr. Eric M. Moyer, ESMO Deputy Project Manager for
Technical
NASA Goddard Space Flight Center

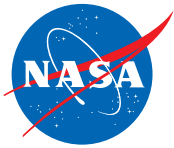
Mr. Wynn J. Watson, ESMO Project Manager
NASA Goddard Space Flight Center

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

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

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

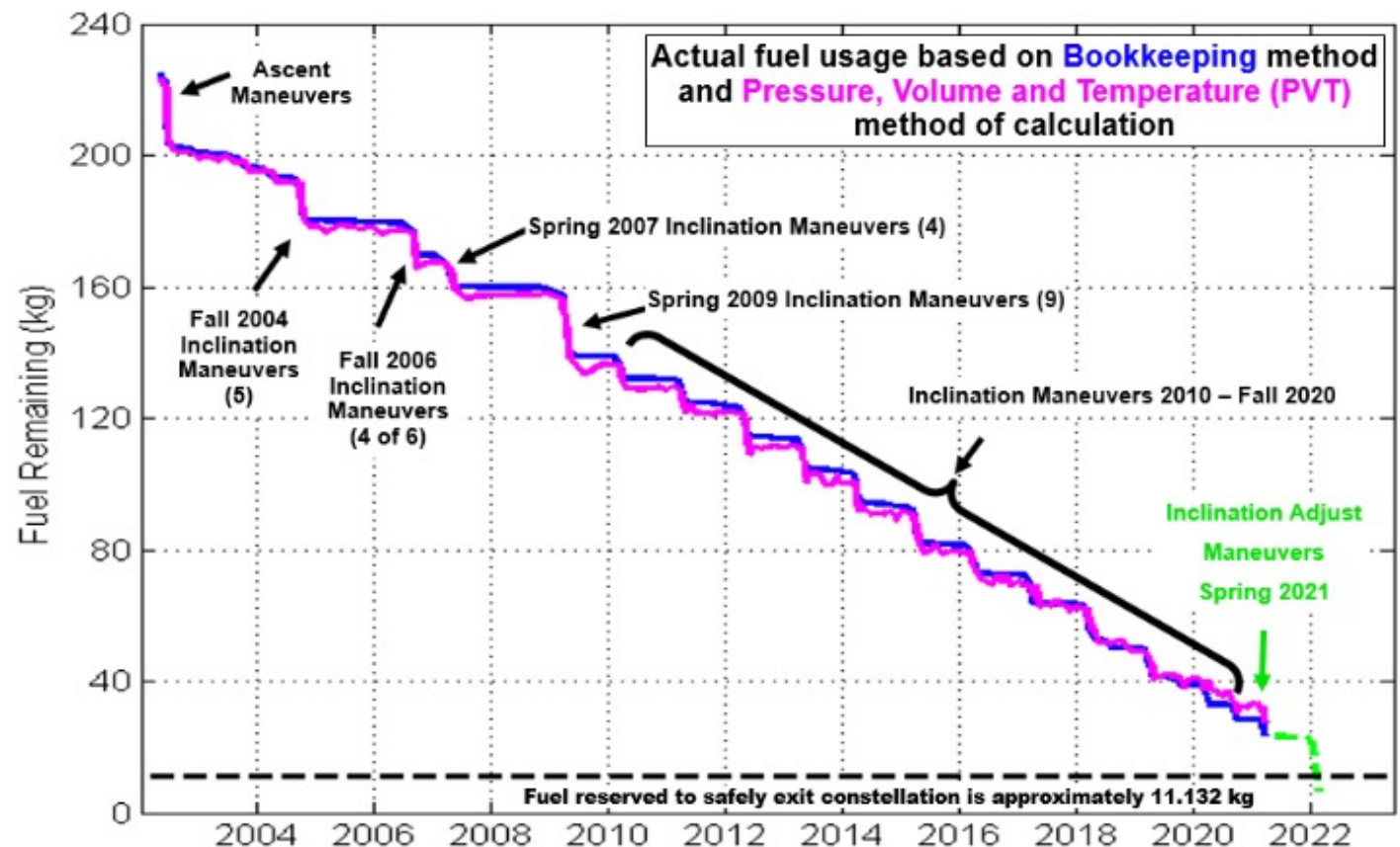
(Photo courtesy of Northrop Grumman/TRW)



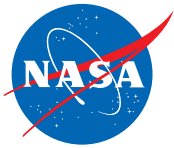
Factors Affecting Aqua's Future

- Funding (e.g., over-guide versus in-guide funding).
- Fuel (needed for spacecraft maneuvers; now greatly depleted).
- Power (needed for instrument operations; reduced after A-Train exit).
- Desire to meet the requirement that the spacecraft's "dwell time" in space after science data collection ends does not exceed 25 years (estimates affected by solar flux calculations).

Timeline of Aqua Fuel Levels



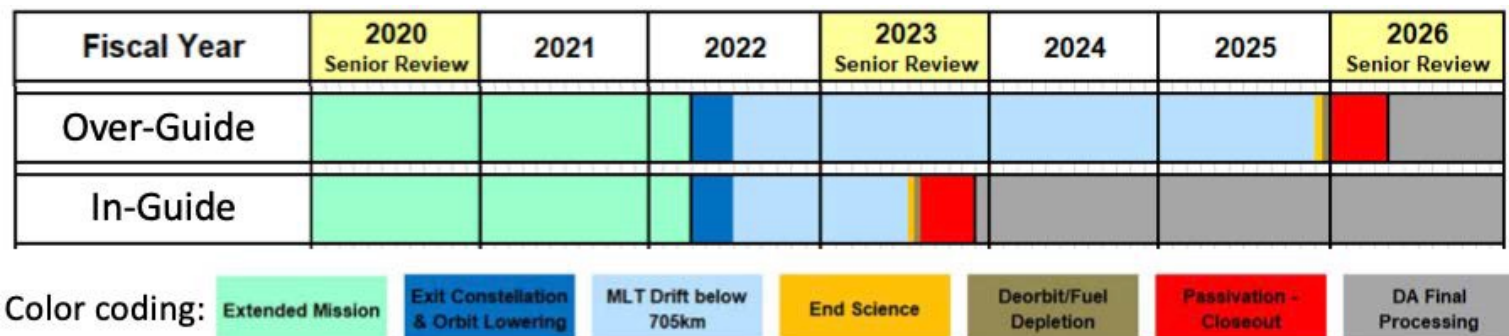
(plot from Bill Guit)

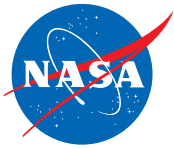


2020 Senior Review Anticipation of Aqua Going Forward

- Continue in the A-Train until January 2022
 - Continue all science and applications.
 - Exit the A-Train in January 2022 due to fuel limitations.
 - Lower the altitude.
 - Allow the mean local time (MLT) of the observations to drift.
- Continue to collect science-quality data after exiting the A-Train
 - Continue most current science and all current applications.
 - Perform new science made possible by the shifting MLTs.
 - End data collection in April 2023 if limited to the in-guide budget.
 - Continue data collection until September 2025 if awarded the over-guide budget.
- Meet end-of-mission requirements.

Alternative Aqua Remaining-Mission Timelines

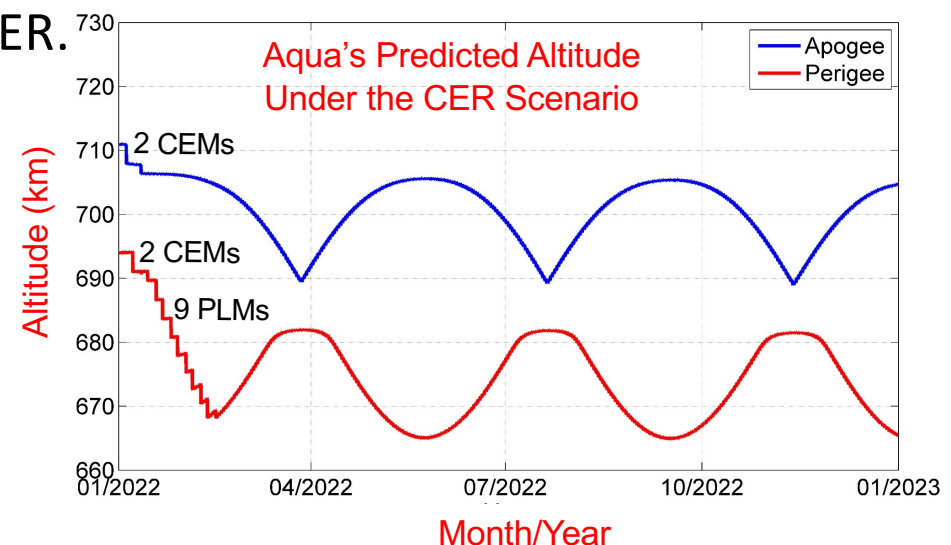


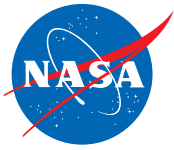


Aqua's Constellation [A-Train] Exit Review (CER), 5/17/21

- Led by the Aqua Mission Director Bill Guit.
- Detailed the planned A-Train exit in early 2022.
 - 4 Constellation Exit Maneuvers (CEMs), January 4, 7, 11, and 14, 2022
 - Lower Aqua to approximately 4.4 km below the A-Train
 - 9 Perigee Lowering Maneuvers (PLMs), from January 18 to February 15, 2022
 - Reserve 0.632 kg of fuel for collision avoidance maneuvers after the A-Train exit
 - No inclination adjust maneuvers (IAMs) or drag make-up maneuvers (DMUs) after the A-Train exit
- Key focus of the review: Orbital safety.
- By mid-June, each of the A-Train missions provided written concurrence with the exit plans presented at the CER.

CEM = Constellation Exit Maneuver
PLM = Perigee Lowering Maneuver

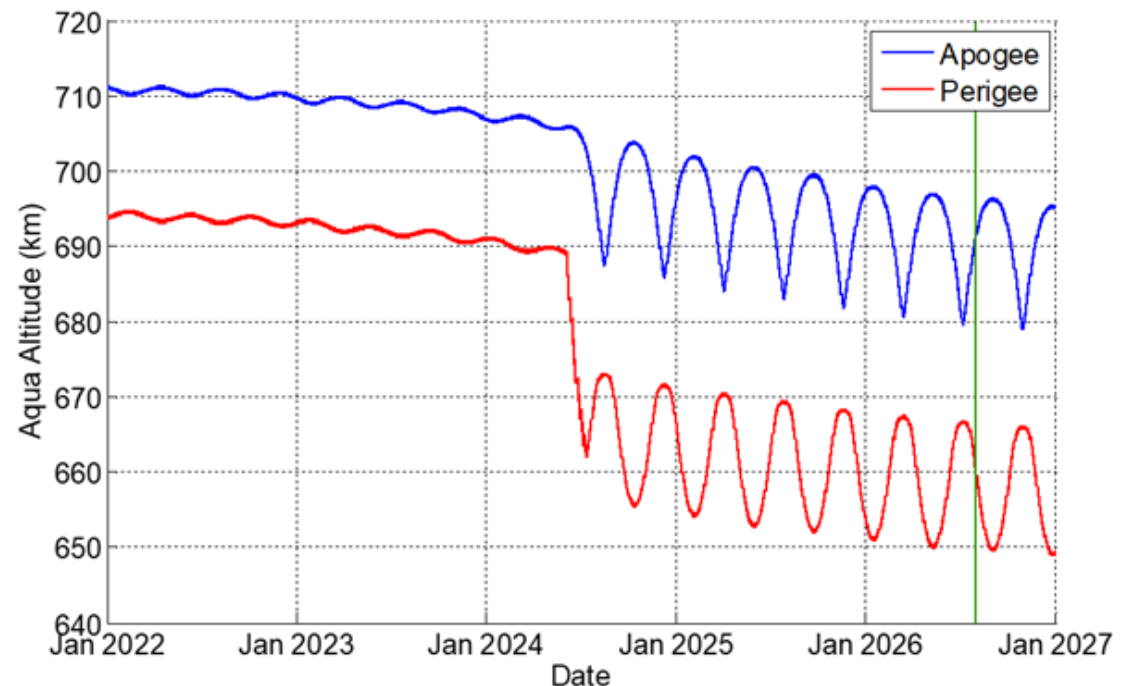




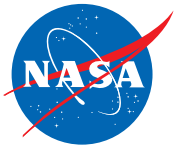
An Improved Option, presented 9/28/21 to the Other A-Train Missions

- Remain in the A-Train in January 2022 but cease inclination-adjust and drag-makeup maneuvers.
- Do not perform constellation exit maneuvers (CEMs).
- Delay perigee lowering maneuvers (PLMs) until June 2024, letting the orbit decay naturally until then.
- End science data collection in August 2026.
- Meet the 25-year dwell-time requirement.

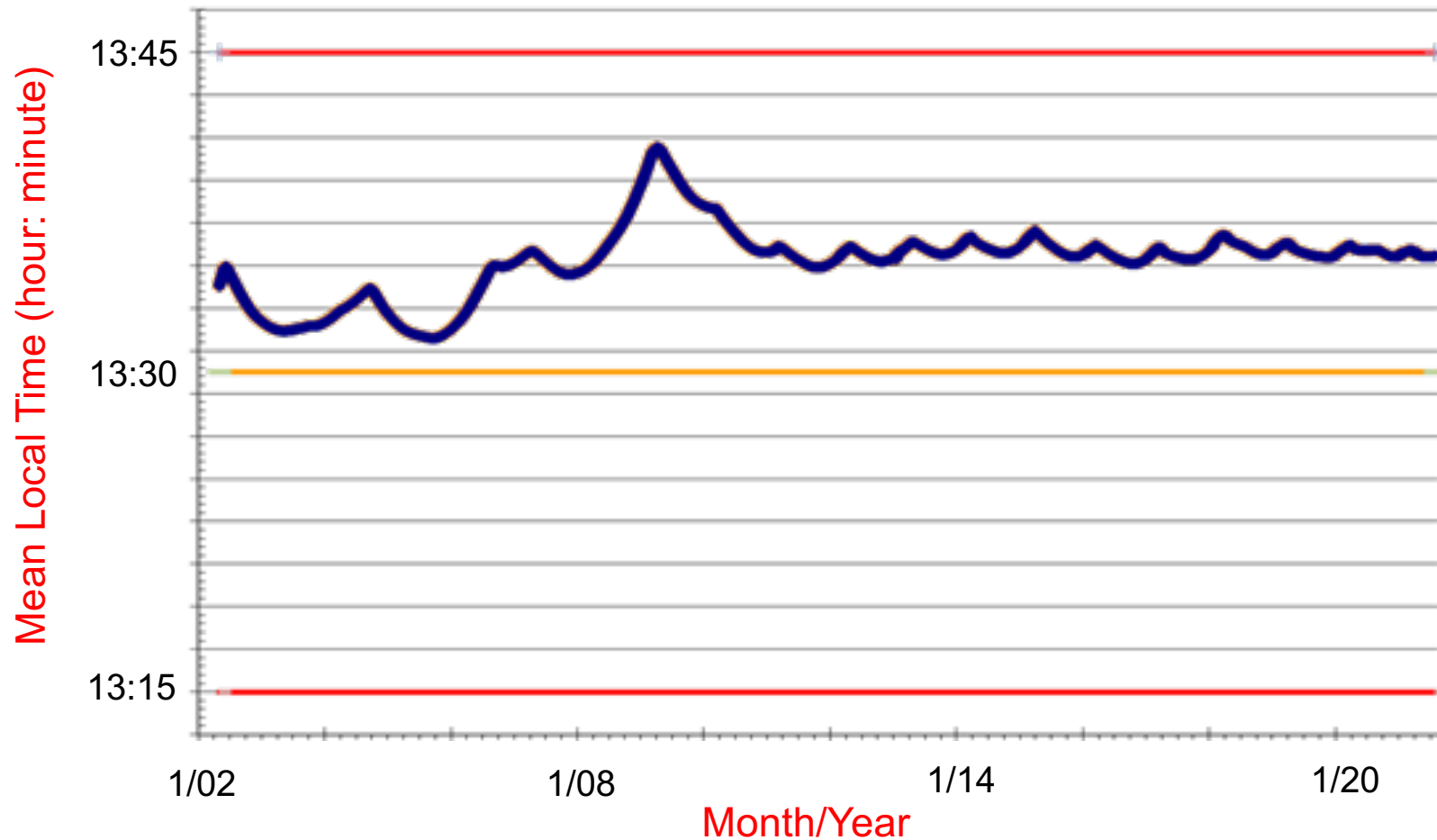
Predicted Aqua Altitude
Timeline if PLMs are
Delayed until June 2024



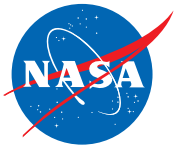
(plot from Flight Dynamics Support Services)



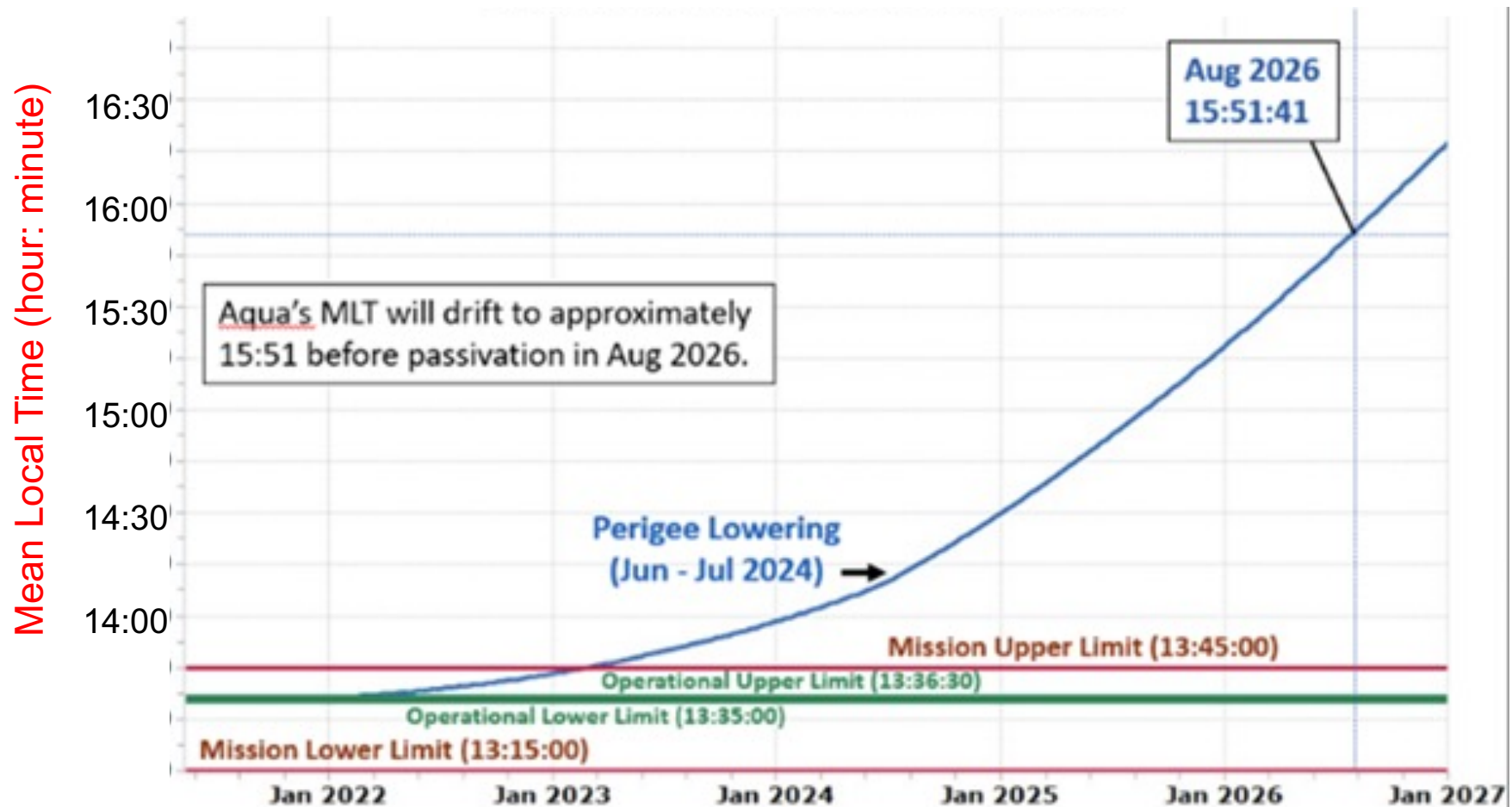
Aqua's Historical Mean Local Time (MLT) at the Northward Equatorial Crossing (Ascending Node)

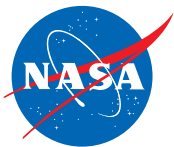


Red lines bound the mission MLT requirements: $13:30 \pm 15$ minutes

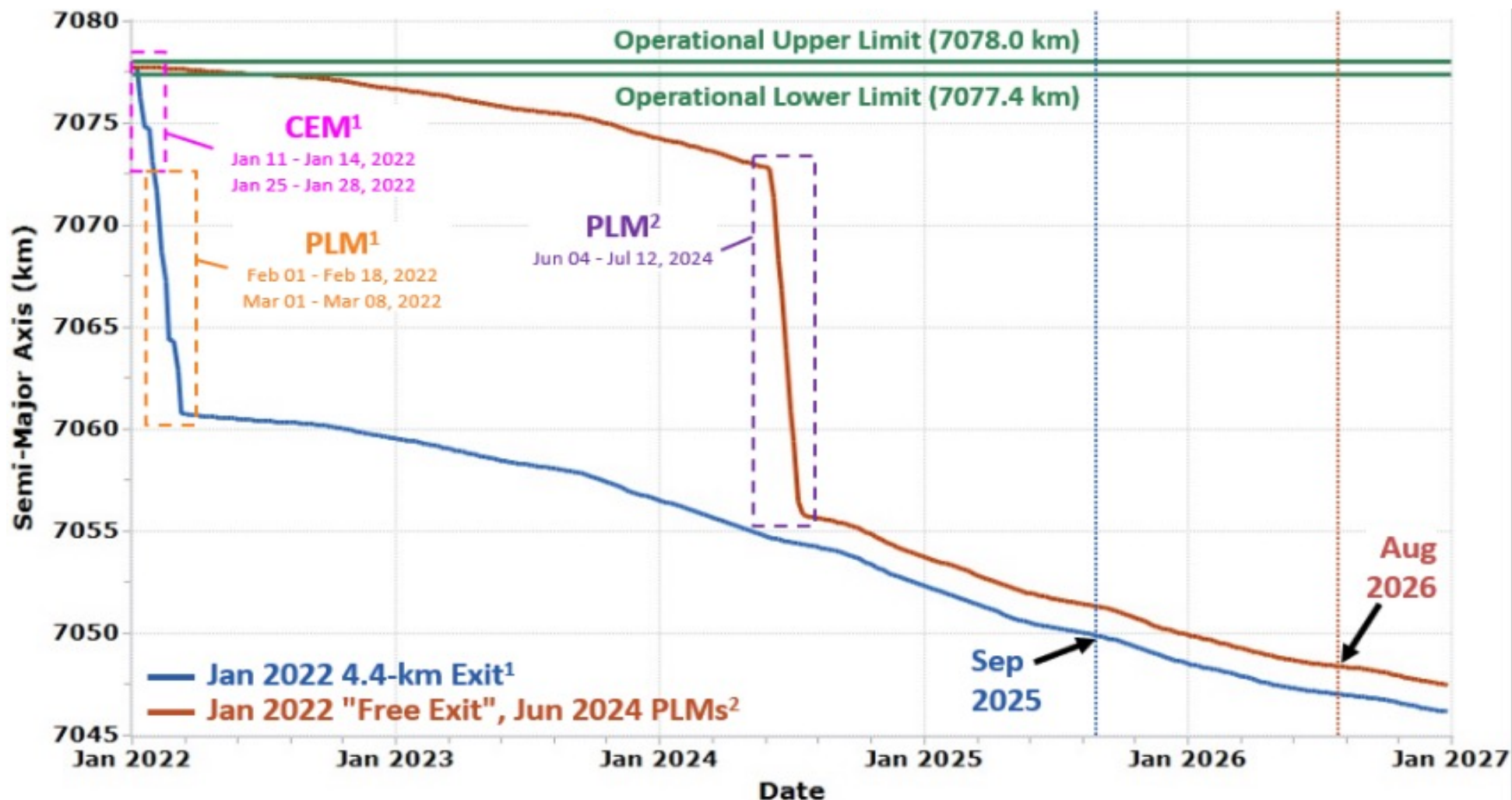


Aqua's Predicted MLT at the Ascending Node If Free-Drift until June 2024, then Perigee Lowering

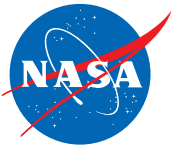




Timeline of Aqua's Semi-Major Axis for Two Options: January 2022 4.4-km A-Train Exit & Free-Drift until June 2024



(from the EOS Flight Dynamics team)

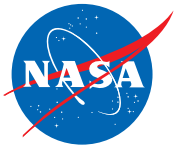


Summary

- After 19 years in orbit, Aqua continues to collect valuable data from AIRS, AMSU, MODIS, and CERES.
- Thousands of people directly use the Aqua data, and millions benefit from the data.
- Fuel limitations will prevent Aqua from maintaining its tight orbit control beyond 2021.
- Plans for Aqua to exit the A-Train in January 2022 have been canceled, replaced by plans to allow Aqua's orbit to decay naturally at least until June 2024.
- Aqua likely can continue to collect valuable science data for several additional years, while drifting to lower altitudes and with later equatorial crossing times.
- Aqua data collection could continue into 2026 or even 2027, dependent on such items as budget, fuel, hardware, power, and end-of-mission requirements.



Aqua pre-launch (courtesy of Northrop Grumman)



References

- Franz, B. A., I. Cetinic, E. M. Karaköylü, D.A. Siegel, and T. K. Westberry, 2019: Global ocean phytoplankton, *Bulletin of the American Meteorological Society*, 100, S92-S93.
- Loeb, N. G., H. Wang, R. P. Allan, and 14 others, 2020: New generation of climate models track recent unprecedented changes in Earth's radiation budget observed by CERES, *Geophysical Research Letters*, 47, doi:10.1029/2019GL086705.
- Susskind, J., G. A. Schmidt, J. N. Lee, and L. Iredell, 2019: Recent global warming as confirmed by AIRS, *Environmental Research Letters*, 14 (4), 044030, <https://doi.org/10.1088/1748-9326/aafd4e>.
- Zou, M., X. Xiong, Z. Wu, S. Li, Y. Zhang, and L. Chen, 2019: Increase of atmospheric methane observed from space-borne and ground-based measurements, *Remote Sensing*, 11, 964, doi:10.3390/rs11080964.