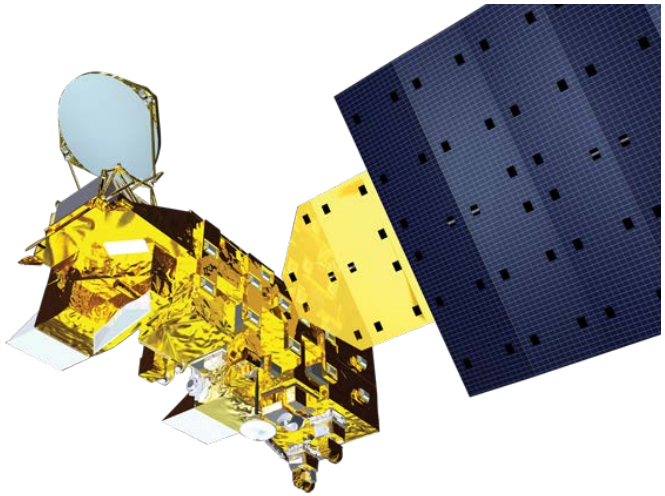


2020 Senior Review of Earth Sciences: Assessment of Aqua

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

Presentation at the MODIS/VIIRS Science Team Meeting,

November 19, 2020

2020 Aqua Senior Review Process

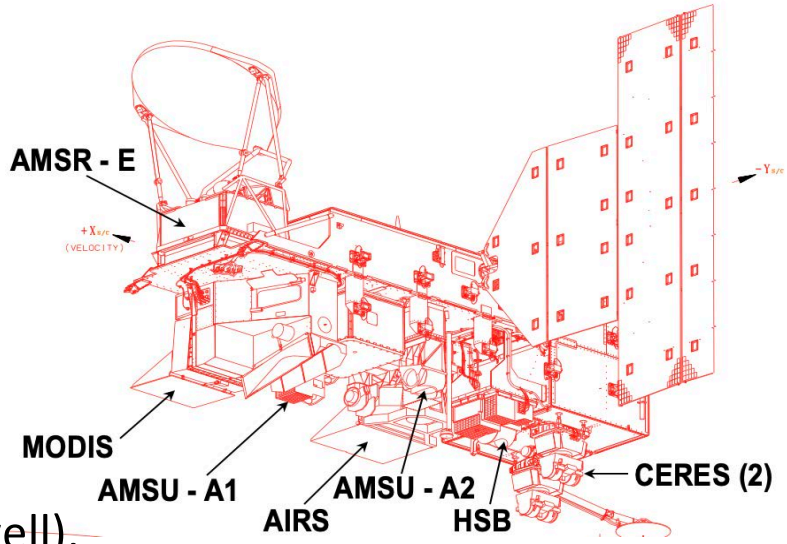
- Received the Call for Proposals from NASA Headquarters (HQ) on 12/20/19.
- Submitted the 280-page Aqua proposal on 3/2/20.
- Received questions from the Technical Panel on 3/19/20.
- Submitted answers to the Technical Panel on 3/30/20.
- Received questions from the Science Panel (and its National Interests and Cost sub-panels) on 5/27/20.
- Provided answers to the Science Panel in a 70-minute presentation on 7/8/20.
- Received the Senior Review Panel Report on 9/21/20.
- Received ”Guidance Letter” from Karen St. Germain/NASA HQ on 10/21/20.

Aqua pre-launch (courtesy of Northrop Grumman)

Senior Review Proposal, submitted 3/2/20

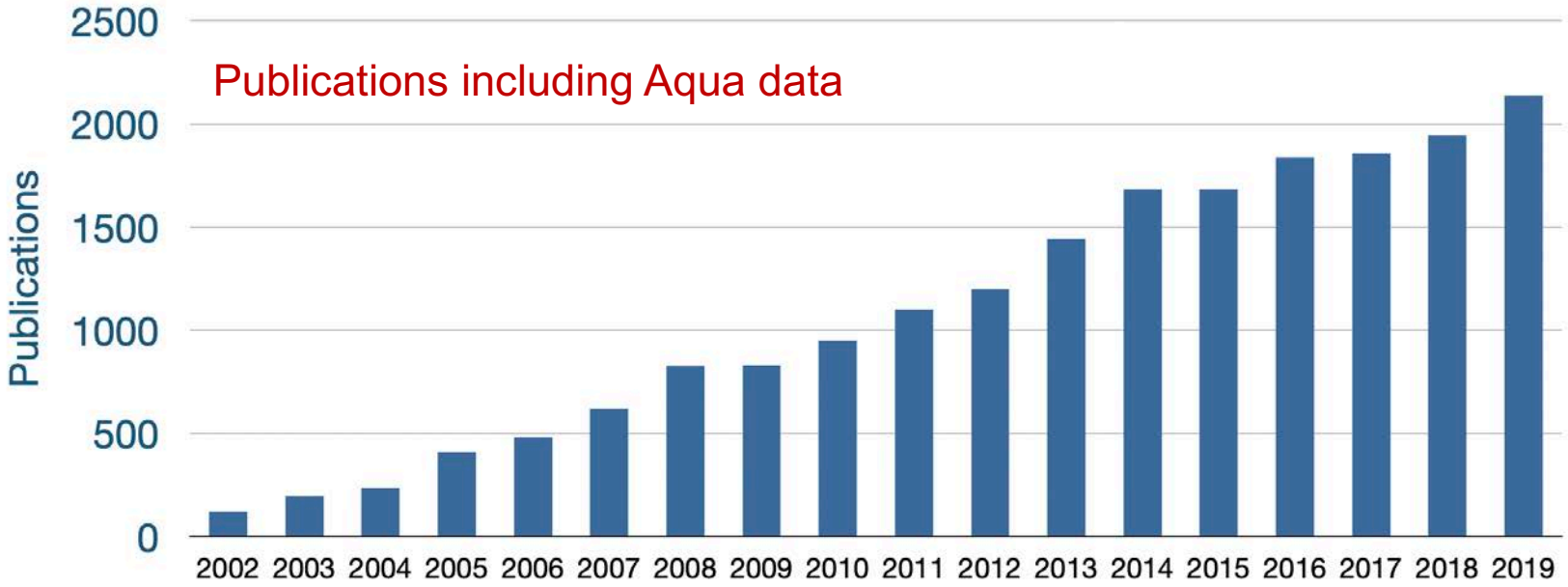
- 280 pages.
- Summarizes the mission
  - Instrumentation.
  - Science.
  - Applications.
  - Algorithm maintenance.
  - Technical status.
  - Future plans.
  - Budget.
- Advocates for mission continuation.
- Provides in-guide and over-guide budget options
  - In-guide: Data collection ends April 2023.
  - Over-guide: Data collection ends September 2025.

Instrument Status



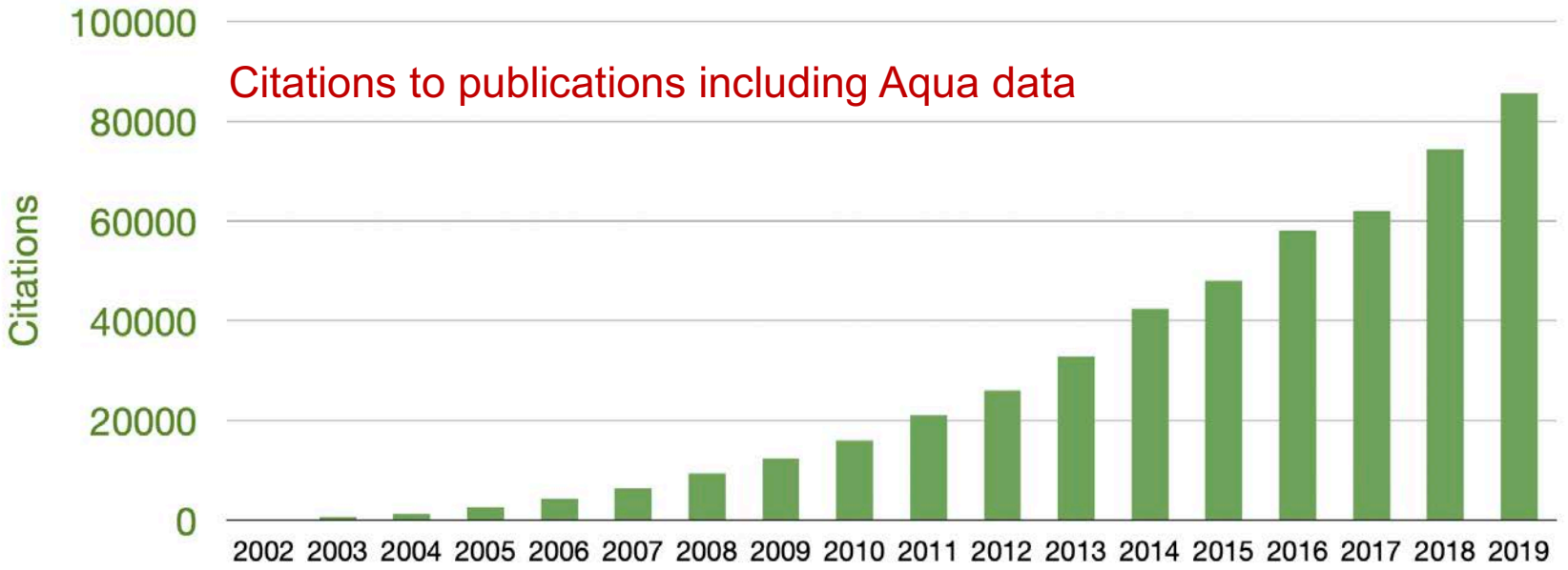
- Atmospheric Infrared Sounder (AIRS)
  - Excellent health.
- Advanced Microwave Sounding Unit (AMSU)
  - Fair health (10 of 15 channels are performing well).
- Humidity Sounder for Brazil (HSB)
  - Provided by Brazil's Instituto Nacional de Pesquisas Espaciais (INPE).
  - Not operating since February 2003.
- Advanced Microwave Scanning Radiometer for EOS (AMSR-E)
  - Provided by the Japan Aerospace Exploration Agency (JAXA).
  - Not operating since March 2016.
- 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.

Aqua's Science Productivity (year by year)



Totals:

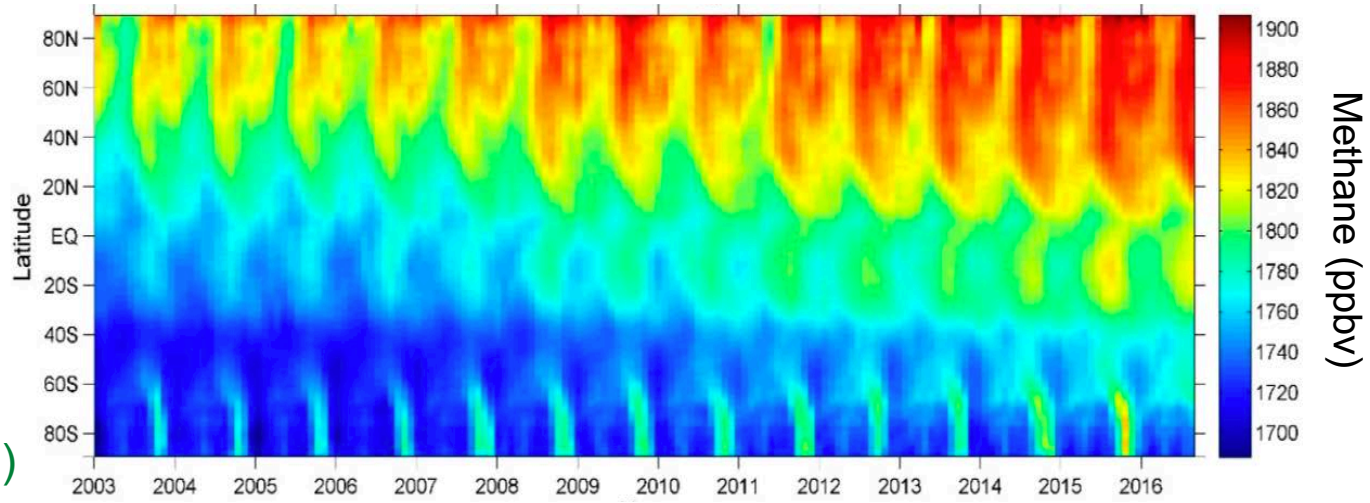
> 19,000



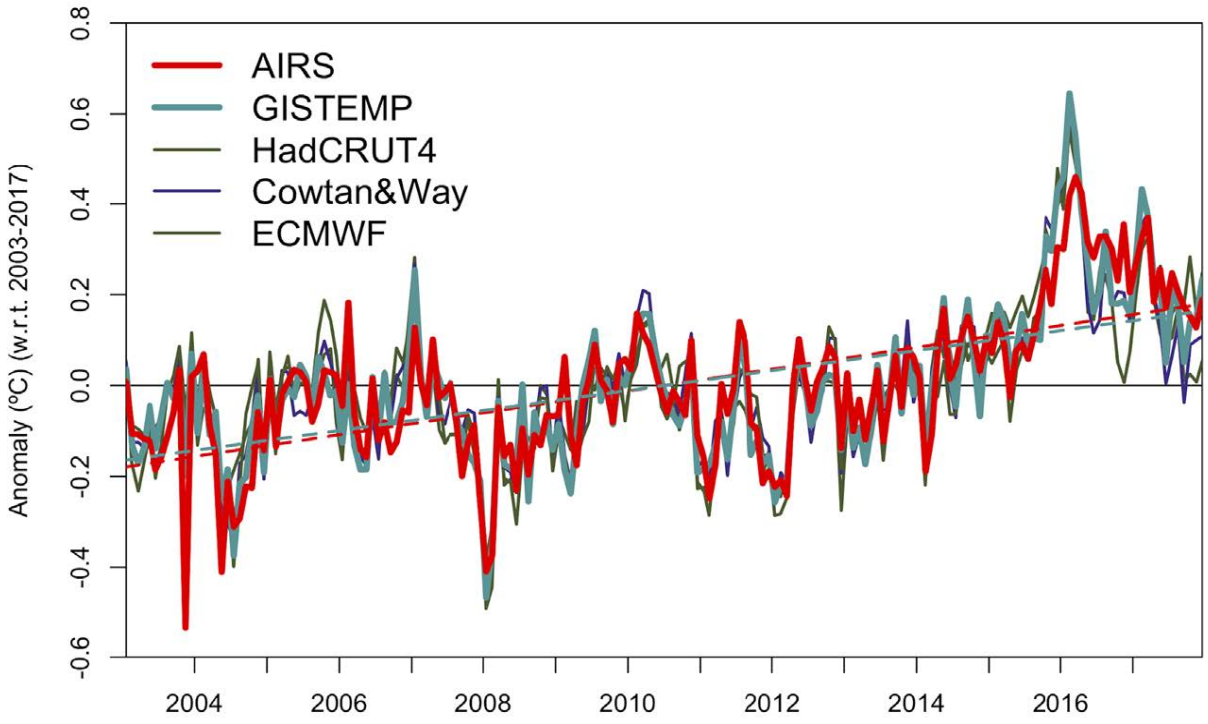
> 498,000

Sample AIRS Science: Greenhouse Gases and Temperature

Zonal tropospheric methane (CH_4) from AIRS



(from Zou *et al*. 2019)



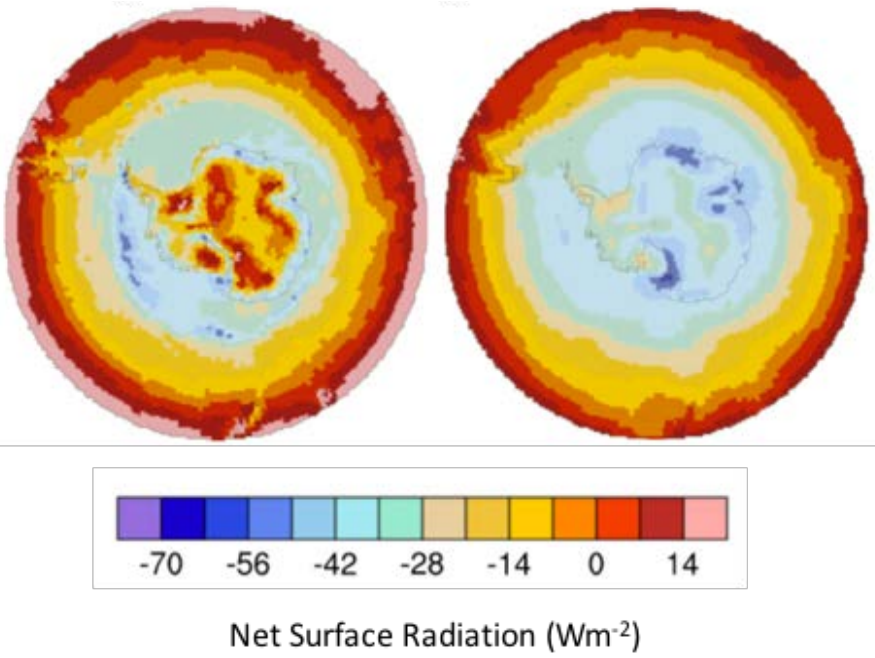
Global monthly mean surface temperature anomalies, 1/2003 – 12/2017, from AIRS and four in situ data sets

GISTEMP = Goddard Institute for Space Studies surface temperature analysis.
HadCrut4 = Hadley Center & Climatic Research Unit temperatures.
Cowtan&Way = Cowtan and Way 2014, *Quarterly J. Royal Meteorological Society.*
ECMWF = European Centre for Medium-Range Weather Forecasts.

(from Susskind *et al.* 2019)

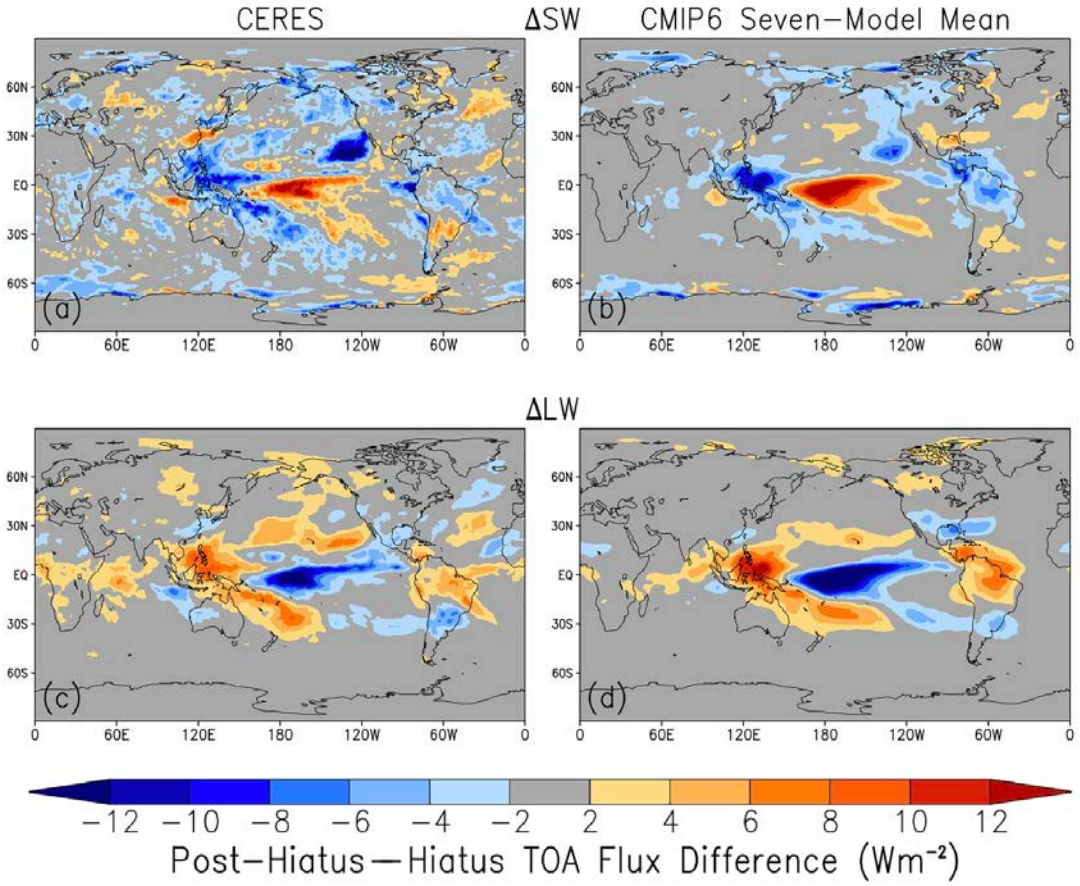
Sample CERES Science:
Use of CERES Data to Test Global Climate Models

Net surface radiation over the Southern Hemisphere, from CERES (left) and models (right)



(from Schneider and Reusch 2016)

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

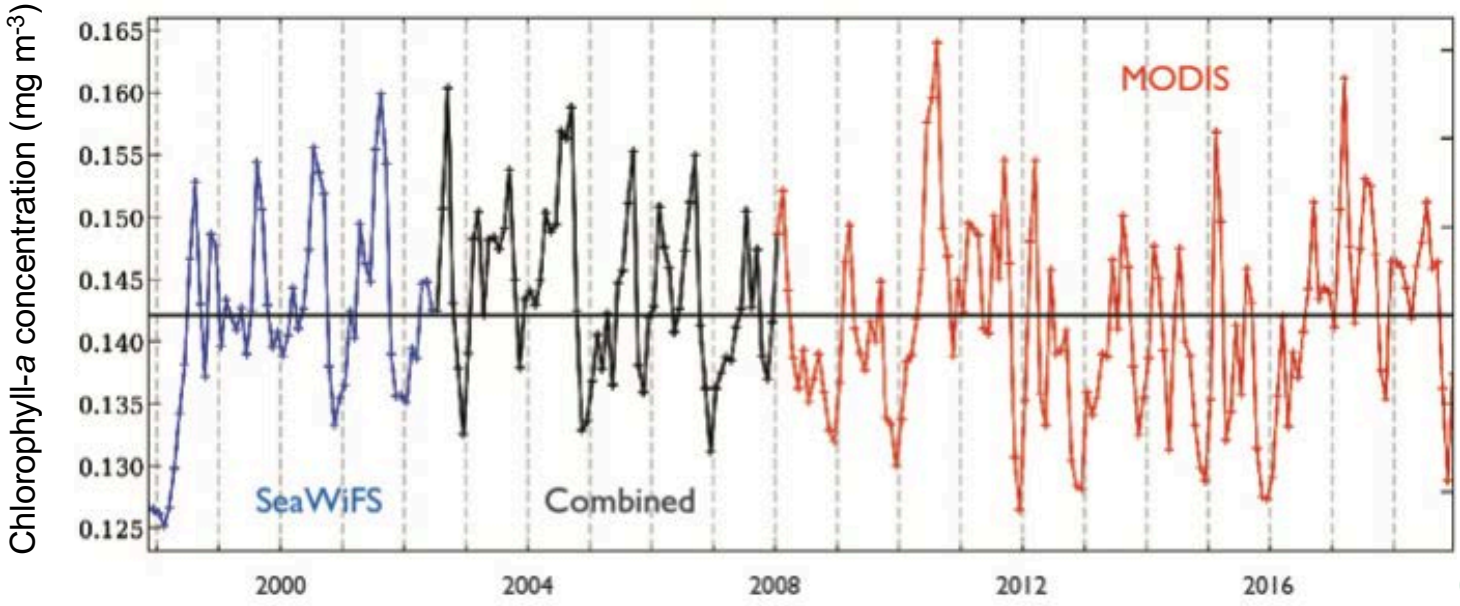


(from Loeb *et al*. 2020)

CMIP6 = Coupled Model Intercomparison Project Phase 6
LW = Longwave; SW = Shortwave
TOA = Top of the Atmosphere

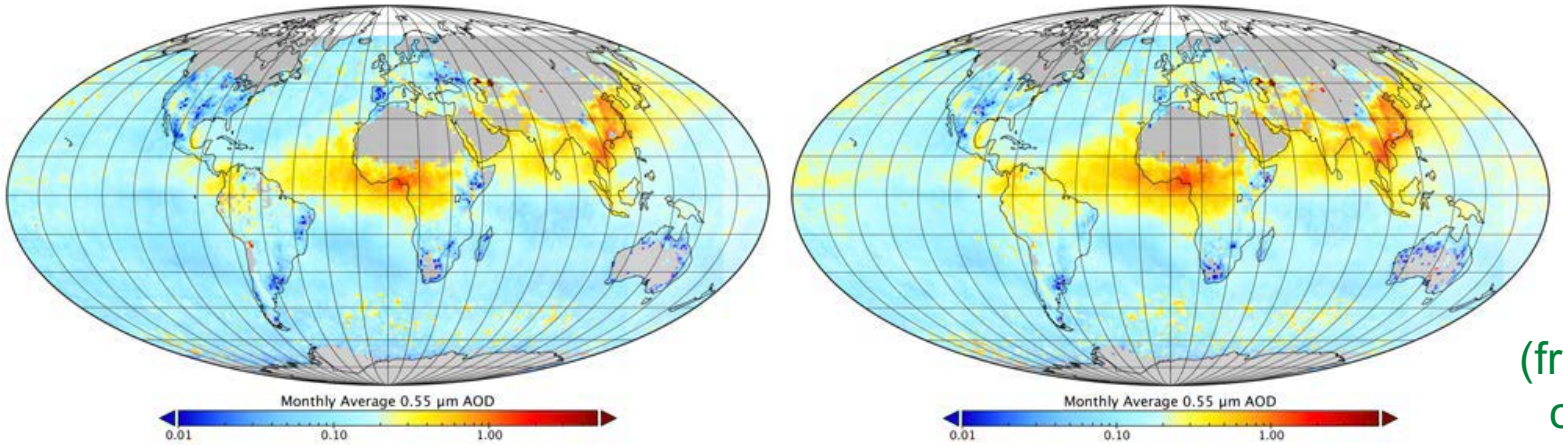
Sample MODIS Science: Linking with Other Data Sets

Chlorophyll-*a* concentration 40°N – 40°S, January 1998 – January 2019, using Aqua MODIS data to extend time series from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS)



(from Franz *et al*. 2019)

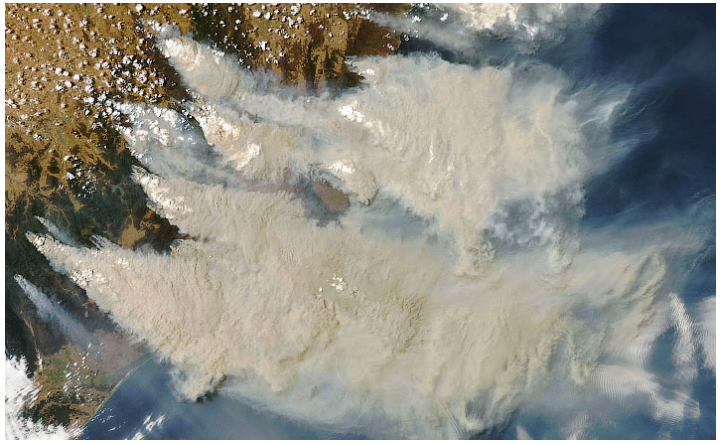
March 2015 aerosol optical depths from Aqua MODIS (left) and VIIRS (right), using the MODIS Collection 6.1 retrieval algorithm



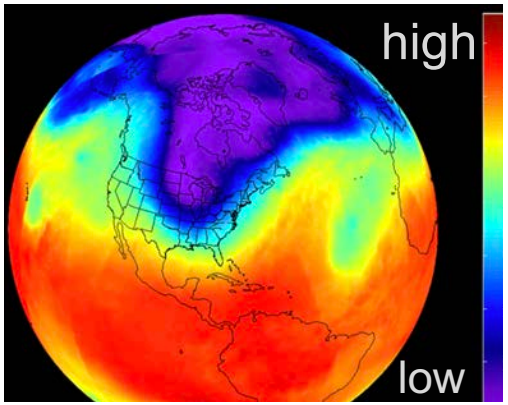
(from Rob Levy, personal communication, 2020)

Sample Applied Uses of Aqua Data

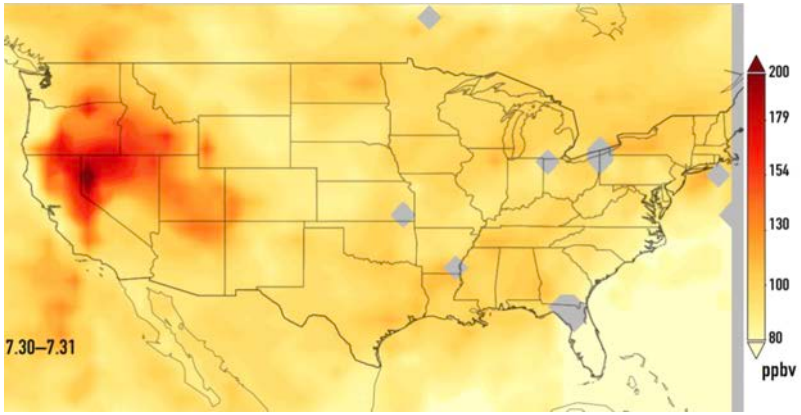
Fires in Australia, 1/4/20, from MODIS

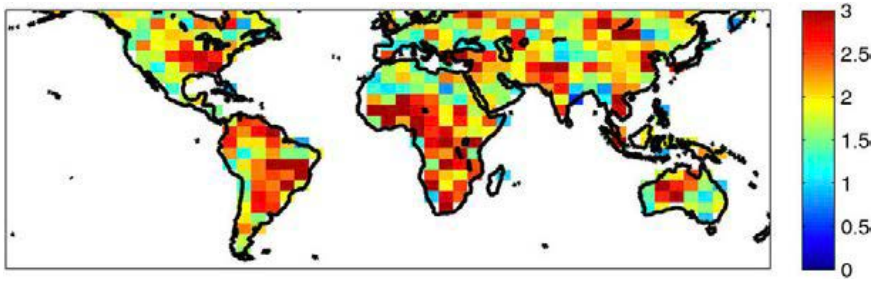


Upper atmospheric temperatures, 1/29/19, from AIRS



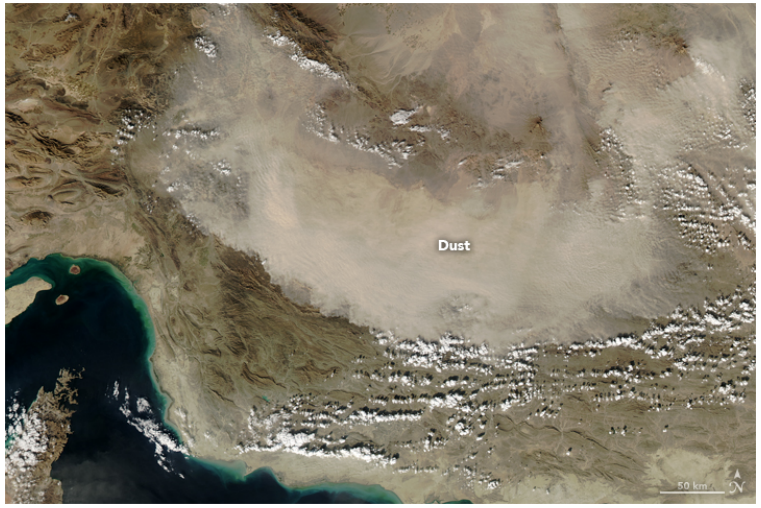
CO from wildfires (ppbv), 7/30/18, from AIRS





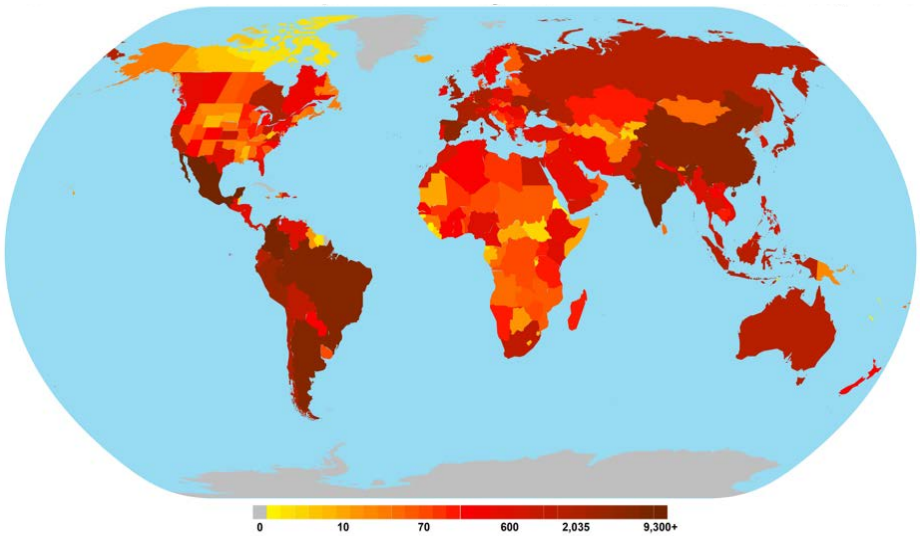
Improved mean lead time (in months) for early drought detection through incorporating AIRS relative humidity data

Dust storm in Iran, 12/10/16, from MODIS

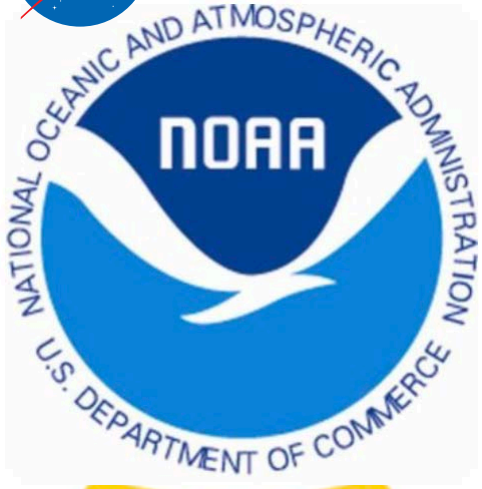


Oil spill, 4/25/10, from MODIS

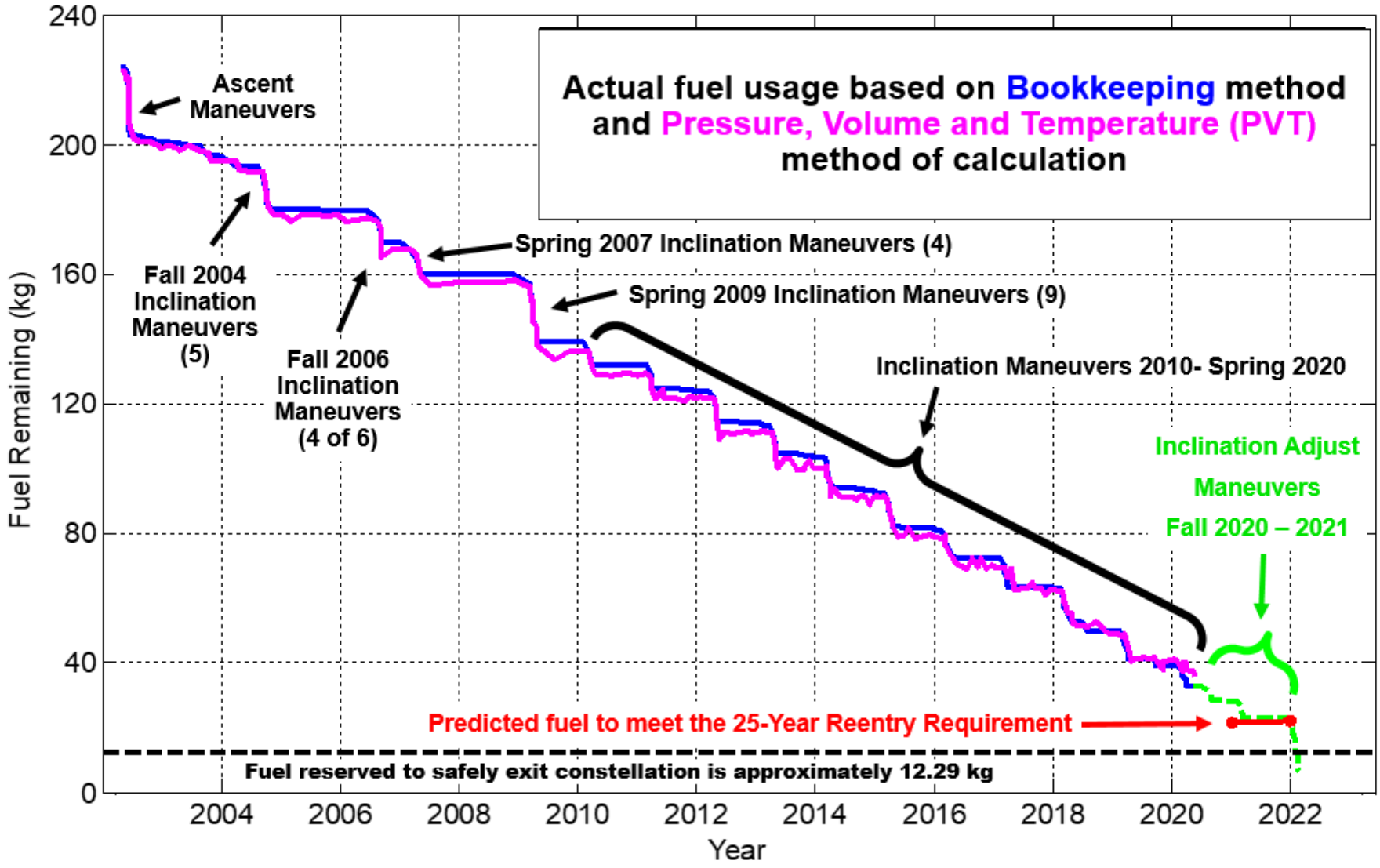
CERES FLASHFlux users, 5/16/18 - 11/30/19

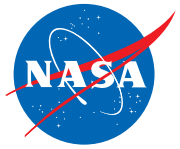


Federal Government Users of Aqua Data



Timeline of Aqua Fuel Levels, Leading to an A-Train Exit Likely in January 2022

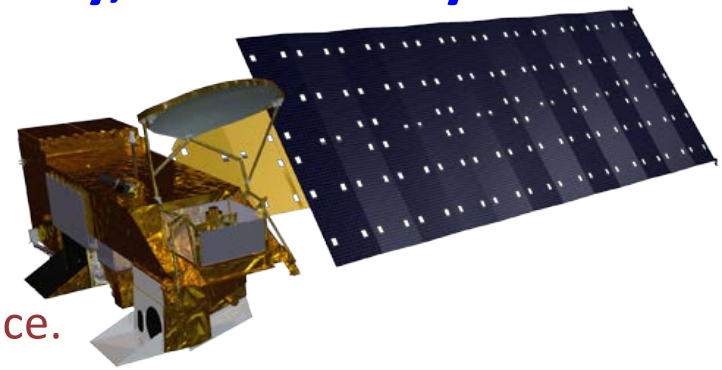




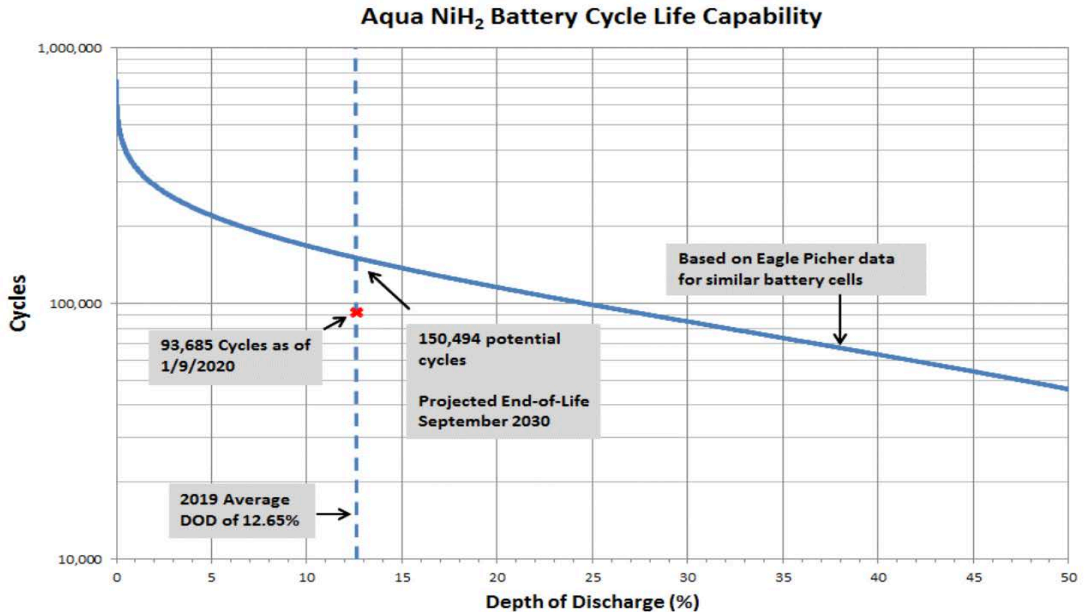
Inclination Adjust Maneuver (IAM) Adjustments to Save Fuel

- Perform autumn as well as spring IAMs, starting in autumn 2019.
- Use reaction wheels rather than thrusters to position the spacecraft for IAMs, starting in spring 2020
  - Saves fuel (also provides more flexibility, allowing smaller, more frequent IAMs and more accurate management of the change in the orbit's semi major axis).
  - Takes longer.
  - Successfully tested on 11/14/19 and successfully performed in March and April 2020.
- Perhaps reduce the number of spring 2021 IAMs from 4 to 3.

Status of the Spacecraft Bus, Solar Array, and Battery



- Aqua Bus
  - Overall status – Excellent.
  - All components remain on primary hardware.
  - One of the four thrusters has degraded performance.
- Aqua Solar Array
  - 111 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.
  - Aqua's anticipated exit from the A-Train in early 2022 will 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 150,494 (or more) Earth orbits, until mid-2030.

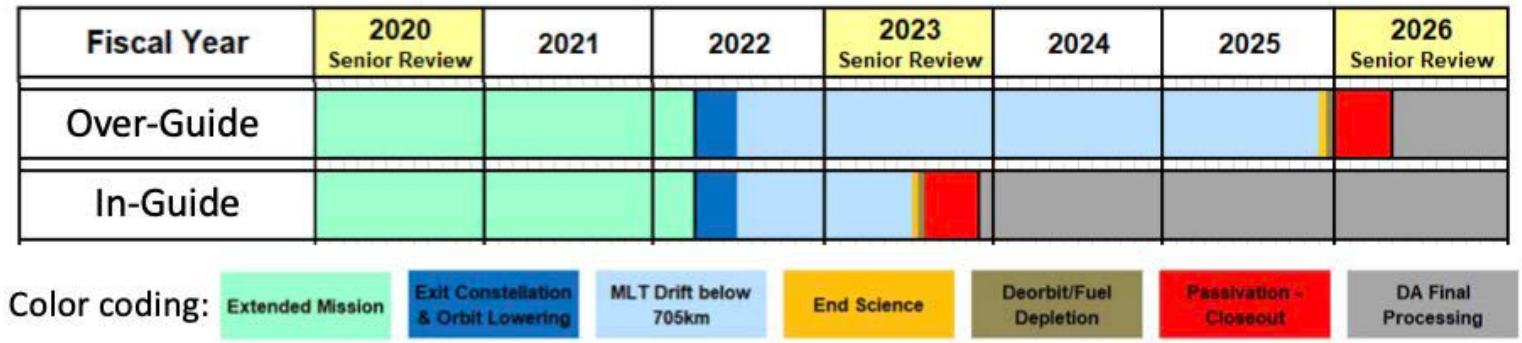


(Aqua visualization by Marit Jentoft-Nilsen; plot based on data from Eagle Picher, the battery's manufacturer)

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



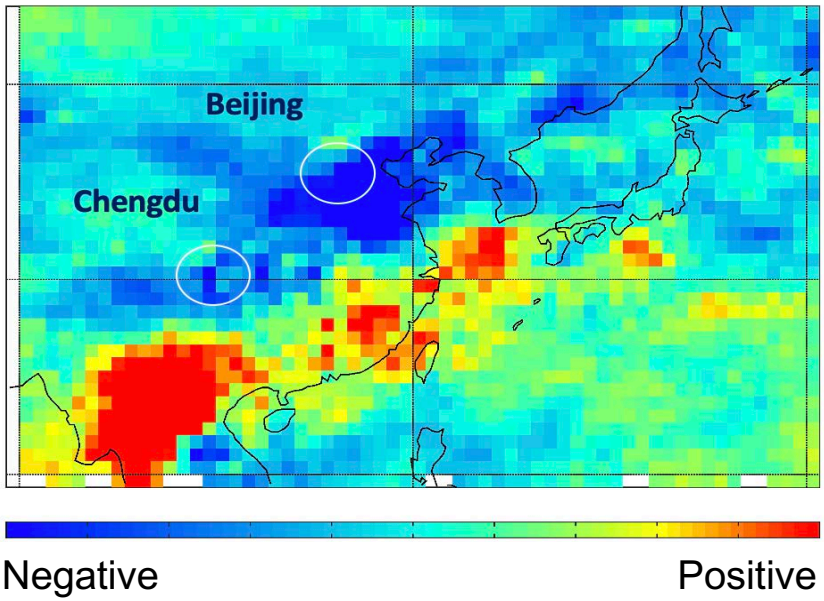
Technical Panel Q & A

- Questions from the Technical Panel came on 3/19/20.
  - Five questions regarding the Earth-observing instruments, including one for MODIS.
  - Four questions regarding fuel.
  - One question regarding the Reaction Wheel Assembly.
- The MODIS question: *Regarding the MODIS instrument, the radiative cooler, for the longer wavelength bands, is reported as having decreased in capability, but then, increased. Please describe why you think this anomaly occurred, and whether it might occur again.*
- Fuel budget summary
  - Estimated 29.74 kg at the end of 2020
  - Estimated 21.77 kg at the end of 2021
  - Estimated 4.70 kg to exit the A-Train
  - Estimated 11.05 kg to lower perigee to 676 km
  - Estimated 6.02 kg fuel buffer.
- Answers provided by the Aqua team on 3/30/20.

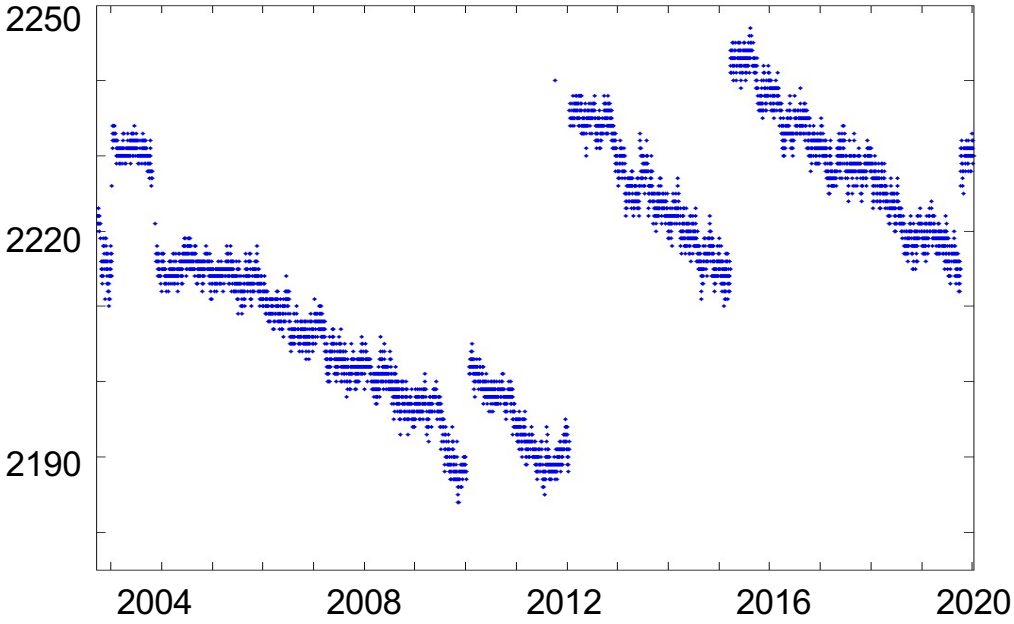
Science Panel Q & A

- Questions and other requests provided by the Panel on 5/27/20.
  - Request for overview and updates
  - Emphasis on the impact of the lowered altitude after exiting the A-Train
  - Questions also on the uniqueness of Aqua data, the risk of having a CERES data gap, and the expected rate of channel degradation in upcoming years for AIRS, AMSU, and MODIS.
- Answers provided in a 70-minute presentation to the Panel on 7/8/20.

Anomalies in February AIRS CO, 2020 versus 2003-2019



Number of Well-Functioning AIRS IR Channels

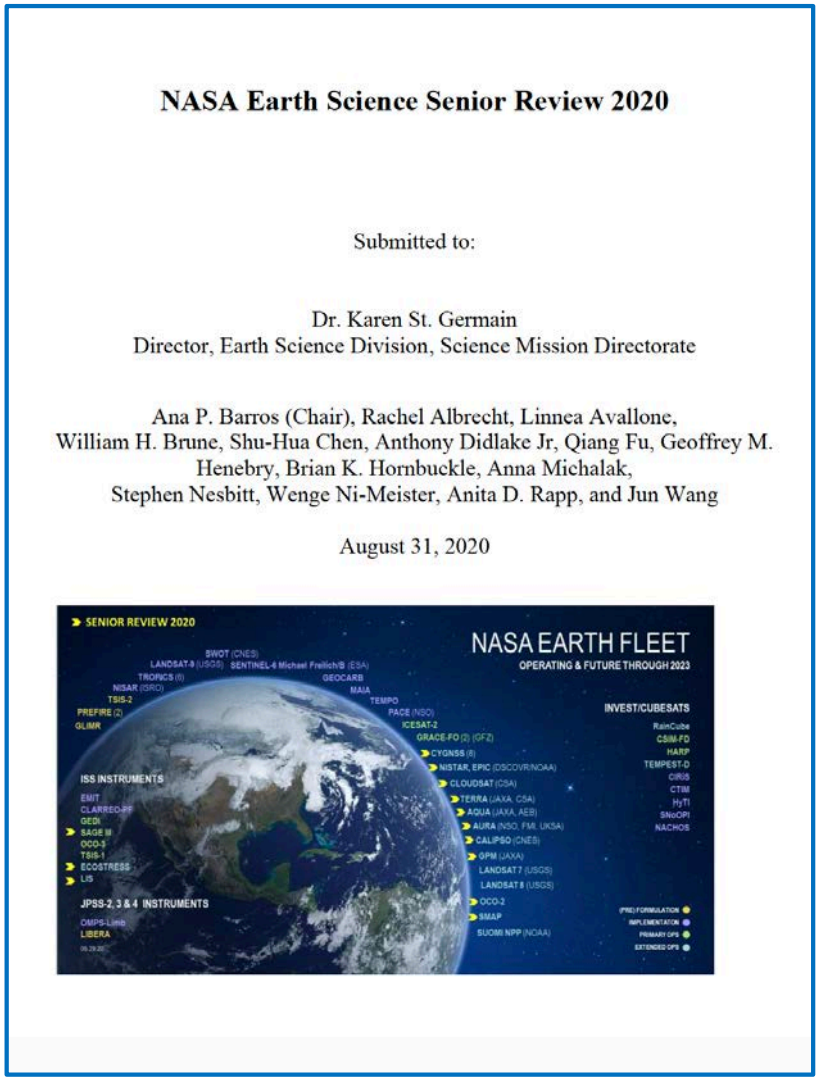


After-the-A-Train Opportunities

- AIRS opportunities
  - Will allow weather prediction centers to assess the impact of infrared (IR) sounders on forecast quality at local times different from current operational IR sounders.
  - Will provide time-of-day information of value in designing new missions.
  - Will result in Aqua measurements in many locations being much closer to the peak time of convection and severe storms, likely improving thunderstorm forecasts and helping to answer key science questions related to convection and storms.
  - Will enhance understanding of diurnal cycles of atmospheric and surface phenomena.
  - Will allow weather and climate model evaluations at different times of day.
- CERES opportunities
  - Will enable continued intercalibration of Aqua, Suomi NPP, and NOAA-20 CERES data, as well as possible overlap with CLARREO.
  - Will enable, when combined with Suomi NPP and NOAA-20 data, highly accurate corrections for orbital drift in the historical record dating back 40 years.
  - Will provide an opportunity to evaluate the diurnal cycle of surface fluxes currently estimated using geostationary imagers.
- MODIS opportunities
  - Will enable examination of: (1) diurnal variations in land surface temperature; (2) fire occurrence and burn scars in mid and late afternoon; (3) solar zenith angle impacts on land and ocean data products.

Report of the Senior Review Panel

- Submitted by the Panel to NASA HQ on 8/31/20; provided by NASA HQ to the Aqua mission on 9/21/20.
- 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

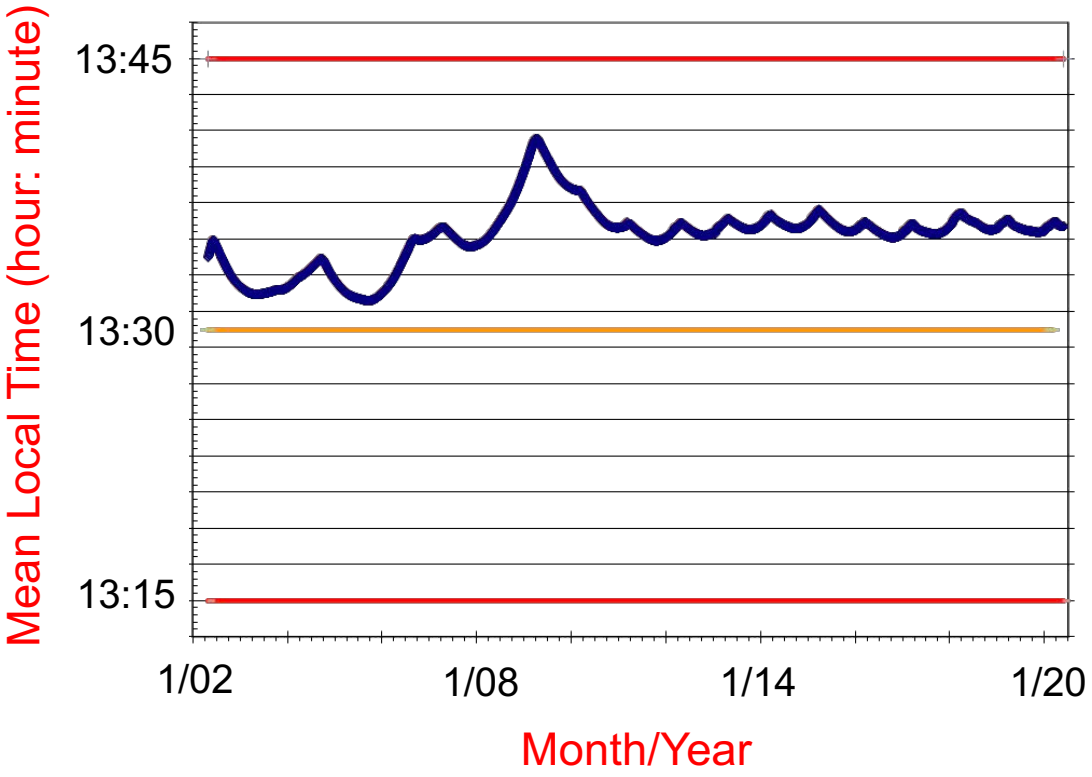
August 31, 2020

"Guidance Letter" from NASA HQ, received 10/21/20

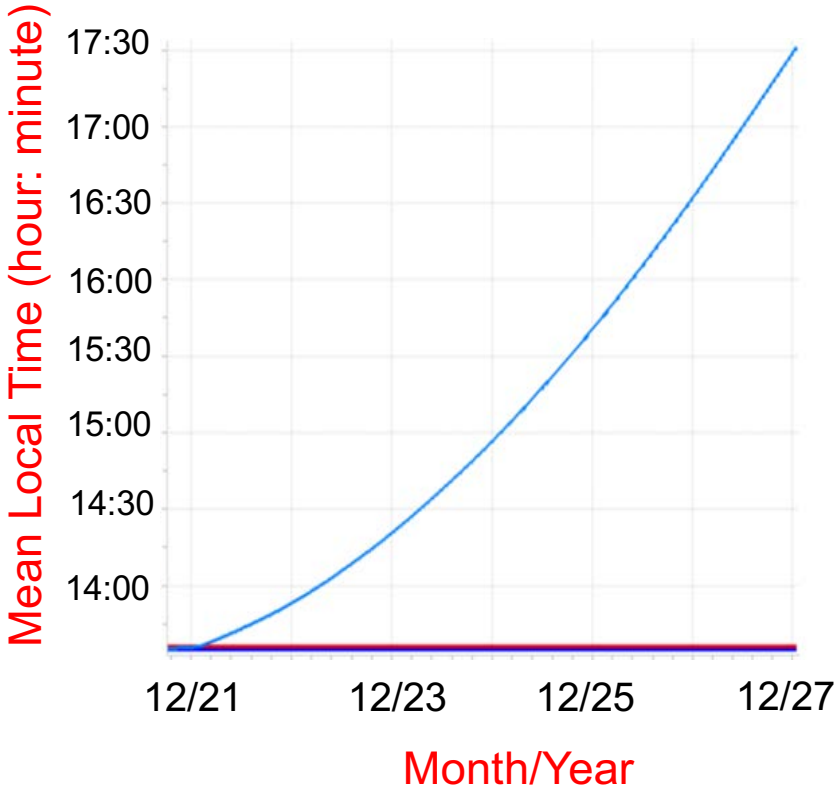
- Praise for the Aqua mission
- Funding decisions
  - In-guide funding for FY21, with no FY21 over-guides for the algorithm maintenance efforts.
  - Over-guide funding for FY22 and FY23.
  - In-guide funding for FY24 and FY25, to be reconsidered through the 2023 Senior Review process.
- Actions Items
  - 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.
  - Update the *Phase F Plan*, for the final years of the mission, after data collection ends.
  - Update the *End of Mission Plan* and the *Mission Operations Plan*.
  - Continue to hold annual Mission Operations Reviews.
  - Submit a 2023 Senior Review proposal.

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

Historical MLT



Predicted MLT



Red lines bound the mission MLT requirements: 13:30 ± 15 minutes

August 16, 2020 Anomaly

- On 8/16/20, suddenly all the data received from the Aqua solid state recorder (SSR) were corrupted.
- Direct broadcast data were still good.
- Earth Science Mission Operations (ESMO) meticulously sorted through possible causes of the anomaly.
- The problem was determined to be in the Formatter Multiplexer Unit (FMU).
- ESMO developed a series of increasingly difficult potential solutions.
- Simulations were done for the simplest potential solution, which would be a reinitialization of the FMU firmware.
- On 9/2/20, the FMU firmware was successfully reinitialized and all the SSR data were back to normal.

Concluding Summary

- 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 likely lead to Aqua's exiting the A-Train in January 2022.
- After its A-Train exit, Aqua could continue to collect valuable science data, at a lower altitude, drifting with later equatorial crossing times, for several additional years.
- Data collection will end in early FY24 under the current budget scenario but could likely continue until September 2025 if an over-guide budget is provided for FY24 and FY25.

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.
- Schneider, D. P., and D. B. Reusch, 2016: Antarctic and Southern Ocean surface temperatures in CMIP5 models in the context of the surface energy budget, *Journal of Climate*, 29, 1689–1716.
- 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.