Aqua @ 20

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Aqua Overview

- Launched May 4, 2002, with a design life of 6 years.
- First satellite in the A-Train and the A-Train’s cornerstone until January 2022; altitude of 705 km; equatorial crossing times of ~1:35 a.m. and ~1:35 p.m.
- Now in a free-drift mode.
- Six Earth-observing instruments, four still operating.
- Data used in thousands of scientific publications and wide-ranging practical applications.
Aqua’s Earth-Observing Instruments

- Atmospheric Infrared Sounder (AIRS)
- Advanced Microwave Sounding Unit (AMSU).
- Humidity Sounder for Brazil (HSB). Provided by Brazil’s Instituto Nacional de Pesquisas Espaciais (INPE).
- Advanced Microwave Scanning Radiometer for EOS (AMSR-E). Provided by the Japan Aerospace Exploration Agency (JAXA).
- Clouds and the Earth’s Radiant Energy System (CERES; two copies).
- Moderate Resolution Imaging Spectroradiometer (MODIS).
Some Major Dates (good and bad) in Aqua’s First 20 Years

• 9/1/2002. Successful end of Aqua’s 120-day checkout period.
• 2/5/2003. HSB data collection ends, due to a scan-mirror motor failure.
• 9/1/2008. Successful end of Aqua’s 6-year prime mission.
• 3/16/2007. Submission of Aqua’s first Senior Review proposal to extend the mission.
• 2/20/2021. Completion of Aqua’s first 100,000 orbits of the Earth.
• 12/1/2021. Aqua’s final drag makeup maneuver, starting its free-drift operations and exit from the A-Train.
Recent Anomalies

(1) Solid State Recorder (SSR) anomaly

- On 2/22/2022, Aqua’s SSR experienced an anomaly resulting in the loss of approximately 19 seconds of AIRS and MODIS data every 2 orbits.
- SSR sub-module 255 was identified as the troublesome sub-module.
- On 3/22/2022, the problem was resolved by marking sub-module 255 as unusable.

(2) Power Controller (PC) anomaly

- On 3/31/2022, the PC for the electrical power subsystem unexpectedly shifted from the primary PC-A to the redundant PC-B, moving it to the B side for the first time.
- Likely a single event upset.
- Successful shift back to PC-A on 4/13/2022.
- Back to nominal operations by 4/15/2022.
Next: A Small Sampling of Aqua’s 20 Years of Observations and the > 20,000 Papers Incorporating Aqua Data, grouped as follows:

• Water Observations from Aqua.
• Climate-Change Observations from Aqua.
• Air-Quality Observations from Aqua.
• Use of Aqua Data to Extend and be Extended by Other Satellite Data Sets.
• Uses of Aqua Data Beyond Science.
Water Observations from Aqua
Sea Surface Temperatures, December 2003, from Aqua MODIS and AMSR-E Data

From MODIS

From AMSR-E
Life and Pollution in the Ocean, from Aqua MODIS Data

Cyanobacteria bloom, Baltic Sea, 7/26/2019
Deepwater Horizon oil spill, Gulf of Mexico, 4/25/2010

2018 chlorophyll-a concentrations (mg m⁻³)

Great Sargassum Belt, July 2018 (from Wang et al. 2019)
Collapse of an East Antarctic Ice Shelf in March 2022, from MODIS Data

(images from https://earthobservatory.nasa.gov)
Sea Ice from AMSR-E Data

Arctic sea ice, 9/14/07

(data from JAXA; image from the NASA Scientific Visualization Studio)
Upper and Lower Atmosphere Water Vapor, January 2003, from AIRS/AMSU Data

(images courtesy of C. Thompson and E. Olsen)
Clouds from Aqua Data

Global mean cloud fraction, 2000 - 2011, from Aqua and Terra MODIS data (from King et al. 2013)

Cloud properties from AIRS/AMSU and MODIS:
- Cloud-top height
- Cloud-top temperature
- Cloud particle phase
- Cloud optical thickness
- Cloud effective radius
- Integrated water path
- Fractional cloud cover

Global clouds, 5/2/22, from MODIS (from worldview.earthdata.nasa.gov)
Global Rainfall Rates, from Aqua AMSR-E and TRMM Data

October 2005 Rainfall from AMSR-E data

October 2005 Rainfall from Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) data

(images from Chris Kummerow and Ralph Ferraro)
Climate-Change Observations from Aqua
Outgoing Shortwave and Longwave Radiation at the Top of the Atmosphere (TOA), from CERES Data

Reflected shortwave (left) and outgoing longwave (right) radiation, 3/18/11, from Aqua CERES data

Global mean TOA flux anomalies, 2000 - 2019, from the Aqua and Terra CERES

(Thin lines: monthly anomalies; thick lines: 12-month running means.)

ENSO = El Nino/Southern Oscillation
LW = Longwave
MEI = Multivariate ENSO Index
SW = Shortwave

(images courtesy of the CERES Science Team; plot from N. Loeb, updated from Loeb et al. 2018)
Net Radiation at the Top of the Atmosphere, May 2009, from CERES on Aqua and Terra and the SORCE Total Irradiance Monitor

SORCE = Solar Radiation and Climate Experiment

(from the CERES Science Team and earthobservatory.nasa.gov)
Mid-Troposphere CO$_2$ as derived from AIRS/AMSU Data

AIRS mid-troposphere CO$_2$ concentrations (ppm) for February 2017 (from Ed Olsen)

CO$_2$ time series from the Mauna Loa Observatory (MLO) and from AIRS retrievals for the Pacific Ocean before and after calibration (from Strow and Hannon 2008)

[An animation of the first 14 years of globally mapped AIRS CO$_2$ concentrations is available from NASA’s Scientific Visualization Studio, at https://svs.gsfc.nasa.gov/4533.]
Zonal Tropospheric Methane ($\text{CH}_4$), 2003-2016, as derived from AIRS Data

(from Zou et al. 2019)
Global monthly mean surface temperature anomalies, 1/2003 – 12/2017, from AIRS data and four in situ data sets

GISTEMP = Goddard Institute for Space Studies surface temperature analysis.
HadCrut4 = Hadley Center & Climatic Research Unit temperatures.
ECMWF = European Centre for Medium-Range Weather Forecasts.

(from Susskind *et al.* 2019)
Arctic Sea Ice Extents, 2002-2011, from AMSR-E Data

(data from JAXA; plot from W. Meier)
Air-Quality Observations from Aqua

(photo from ImageVortex.com)
Sample Visible Air Quality Issues Seen in Aqua MODIS Imagery

Dust Storm in the Middle East, 4/24/22

Volcanic ash from Iceland’s Eyjafjallajökull volcano, 5/10/10

Fires and smoke from South Korea, 3/5/22

Smoke from Australian fires, 1/4/20
Mt. Etna Eruption, October 28, 2002, from AIRS Data

Visible/Near IR image

IR difference image highlighting SO$_2$

(images courtesy of M. Chahine and the AIRS Science Team)
Atmospheric Carbon Monoxide (CO) from AIRS Data

CO from California wildfires (ppb), 7/30/18

Northern Hemisphere (NH) atmospheric CO, 2002-2019, from AIRS and MOPITT

---MOPITT: -0.56 ± 0.3% p.y.
---AIRS: -0.61 ± 0.2% p.y.

Beijing
Chengdu

Anomalies in February atmospheric CO over Beijing and surroundings, 2020 versus 2003-2019, from AIRS data (from the AIRS Science Team)

MOPITT = Measurements of Pollution in the Troposphere (on Terra)
ppb = parts per billion
ppbv = parts per billion by volume
p.y. = per year
Use of Aqua Data to Extend and be Extended by Other Satellite Data Sets


(from Franz et al. 2019)

Arctic sea ice extents, 2002-2021, using AMSR2 data to extend the AMSR-E record

(data from JAXA; plot from W. Meier)
Uses of Aqua Data Beyond Science
“The AIRS instrument has provided the most significant increase in forecast improvement in this time range of any other single instrument.” — 2005 quote from the NOAA Administrator Conrad C. Lautenbacher, Jr.

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

(plot from Wallace McMillan; map from the AIRS Science Team; titles added)
Federal Government Users of Aqua Data
Number of Users of CERES FLASHFlux Data Products, 5/16/18 – 11/30/19

FLASHFlux = Fast Longwave and Shortwave Radiative Flux
January 2022, Aqua begins its free-drift orbit, slowly lowering its altitude and allowing the MLT to drift.

June-July 2024, Aqua executes orbit (perigee) lowering maneuvers.

August 2026, Aqua Instrument Shutdown & Spacecraft Passivation (Power generation is now the anticipated life-limiting factor for the Aqua Mission).

Historically, since May 2002, Aqua's mean local time has always been between 13:30 and 13:45, i.e., between 1:30 p.m. and 1:45 p.m.
Anticipated Future Possibilities (if funding and hardware durability allow)

• Further extension of the Aqua data sets, conceivably until August 2026.
• Continued overlap with current missions and anticipated overlap with new missions, enabling extension of the data sets beyond the period of Aqua data collection.
• Exciting new possibilities with the now-drifting mean local time.
  – Enhance understanding of diurnal cycles of atmospheric and surface phenomena.
  – Allow weather prediction centers to assess the impact of observations from different times of day.
  – Obtain data closer to the peak time of convection and severe storms, helping address key science questions on these topics.
  – Provide time-of-day information of value in designing new missions.
  – Enable accurate corrections for orbital drift in the historical record of various data sets.