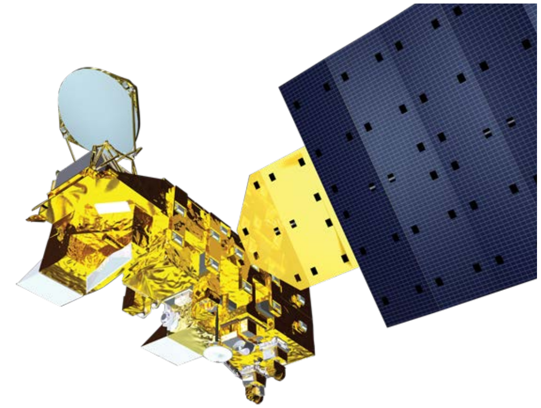


Aqua @ 20

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

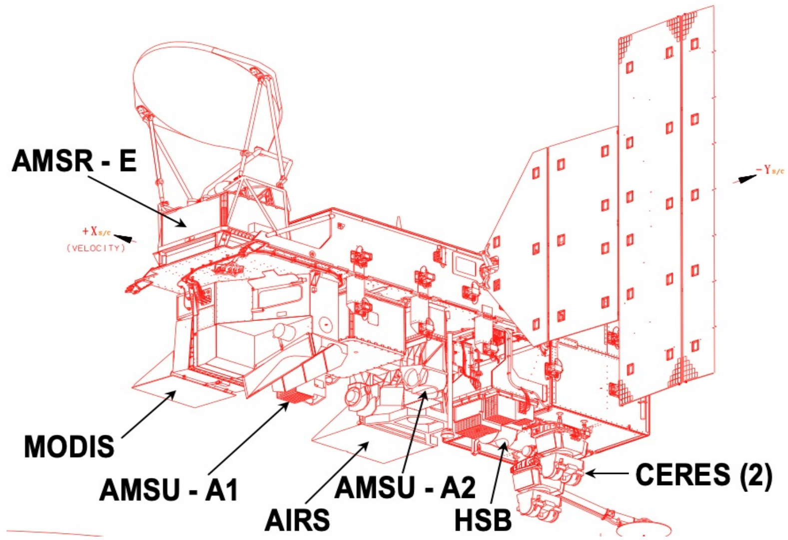
Presentation at the NASA AIRS/Sounder Science Team Meeting,
given online, May 10, 2022

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.

(photo of the Aqua launch by Bill Ingalls)

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).

Aqua pre-launch (courtesy of Northrop Grumman)

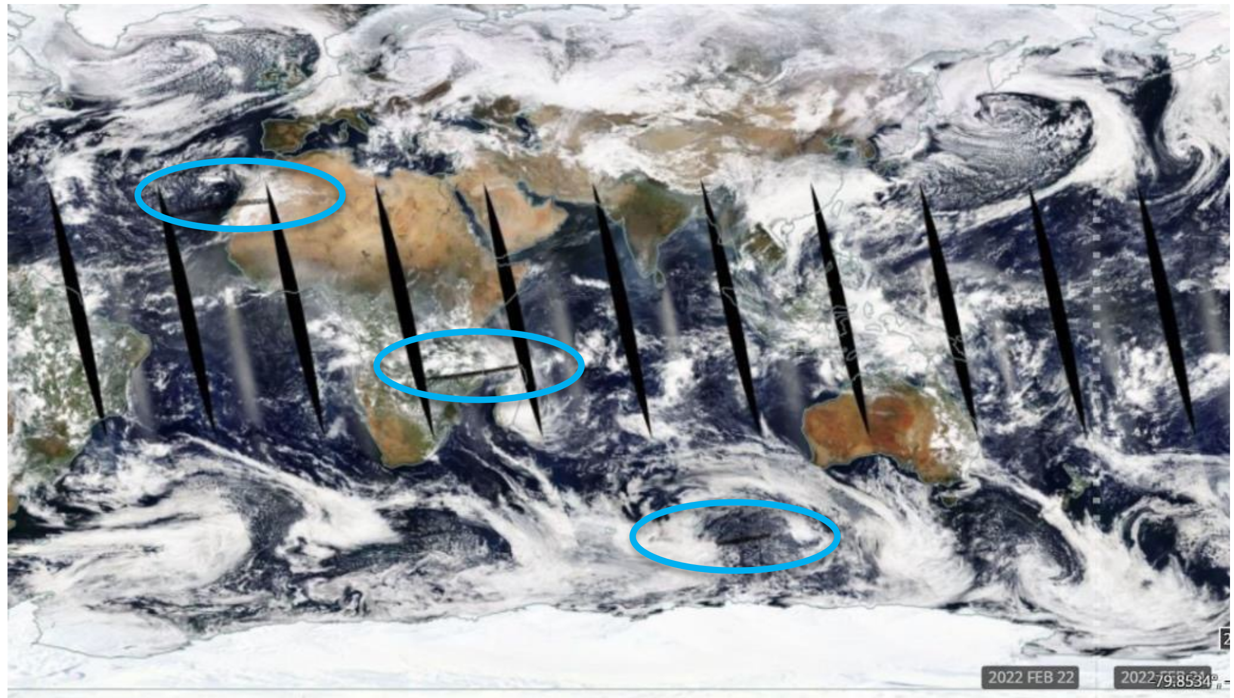
Some Major Dates (good and bad) in Aqua's First 20 Years

- 5/4/2002. Launch.
- 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.
- 7/15/2004. Aqua joined by Aura in the A-Train.
  - Subsequently joined by PARASOL (12/18/2004-12/2/2009), CloudSat (4/28/2006-2/22/2018), CALIPSO (4/28/2006-9/13/2018), GCOM-W (5/18/2012), and OCO-2 (7/2/2014)
- 9/1/2008. Successful end of Aqua's 6-year prime mission.
- 12/2/2008. Successful End-of-Prime-Mission Review.
- 3/16/2007. Submission of Aqua's first Senior Review proposal to extend the mission.
  - Subsequent Senior Review submissions: 3/24/2009 , 3/4/2011, 3/1/2013, 3/3/2015, 3/1/2017, 3/2/2020.
- 10/4/2011. AMSR-E science-quality data collection ends.
  - 12/4/2012. Restart of AMSR-E, rotating at 2 (versus 40) revolutions per minute.
  - 3/3/2016. AMSR-E powered off, after 3 years of cross-calibration with GCOM-W's AMSR2.
- 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.
- 4/3/2021. Aqua safely passed under GCOM-W, for its first passage under an A-Train satellite.

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.



WorldView Aqua MODIS image, 2/22/2022

(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.

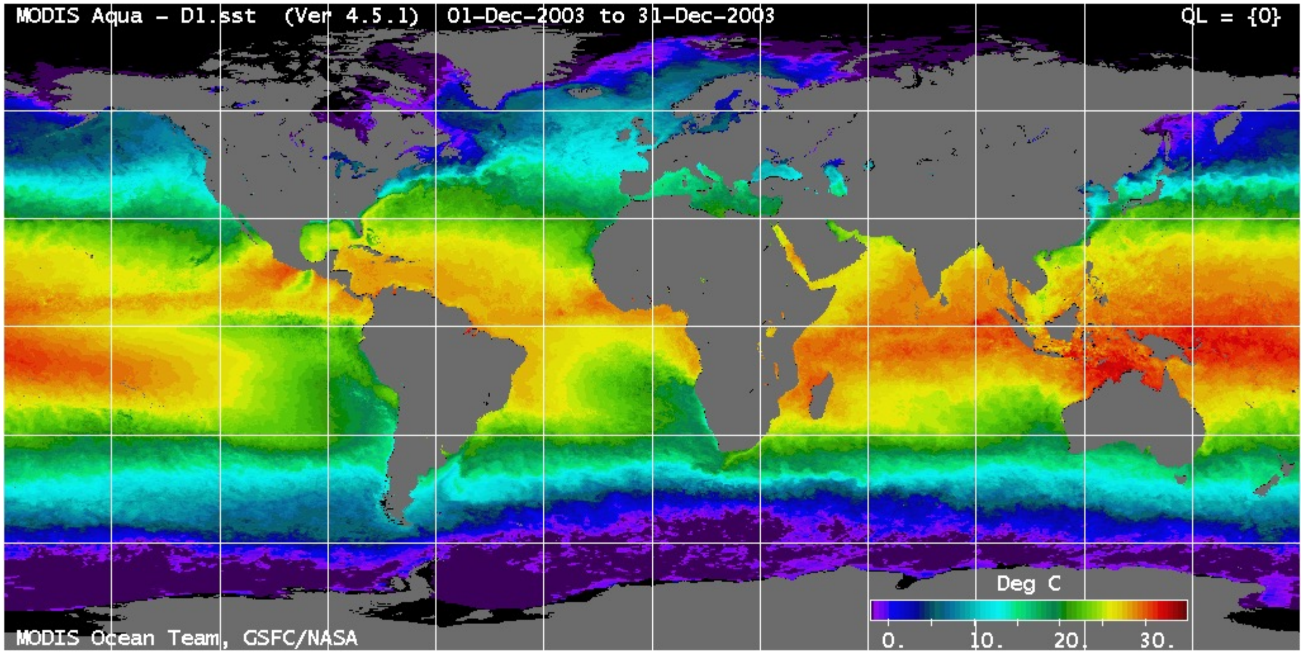
Next: A Small Sampling of Aqua's 20 Years of Observations and the > 20,000 Papers Incorporating Aqua Data, grouped as follows:

- 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.

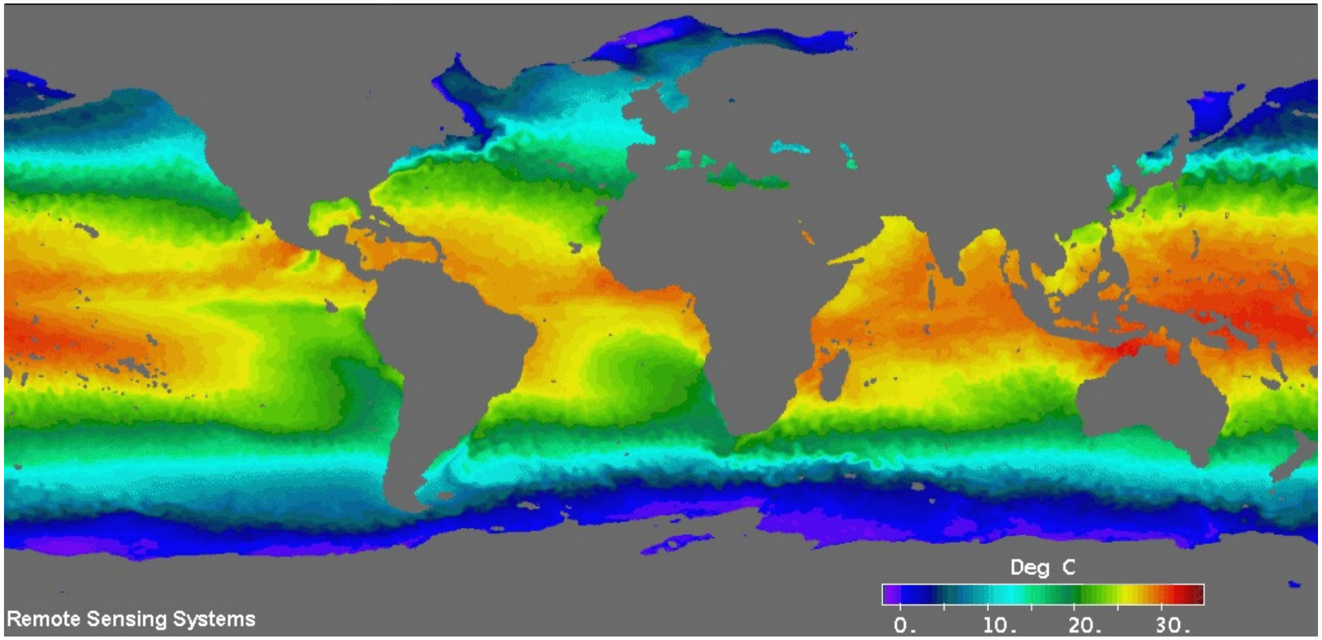
Water Observations from Aqua

Sea Surface Temperatures, December 2003, from Aqua MODIS and AMSR-E Data

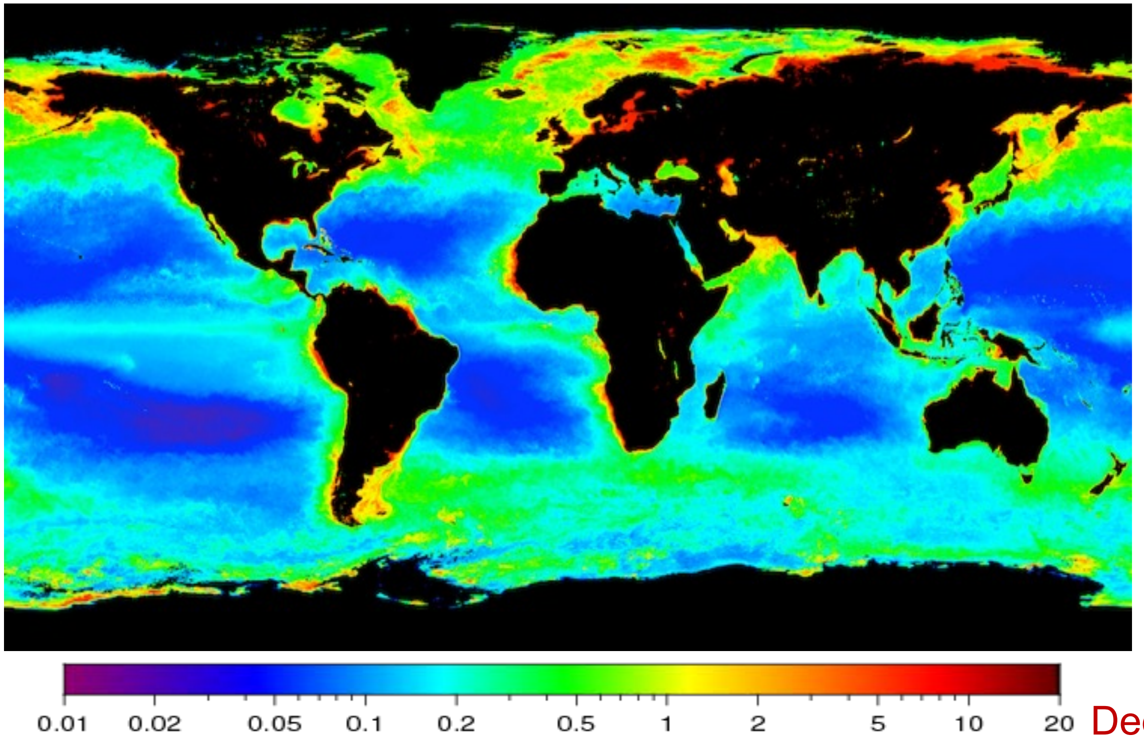
From MODIS



From AMSR-E



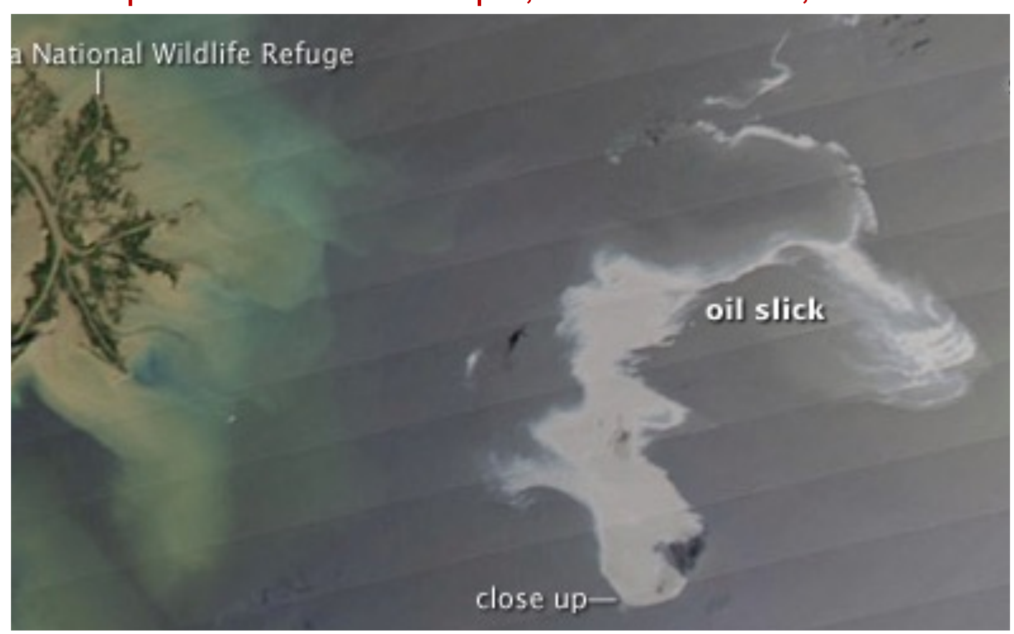
Life and Pollution in the Ocean, from Aqua MODIS Data

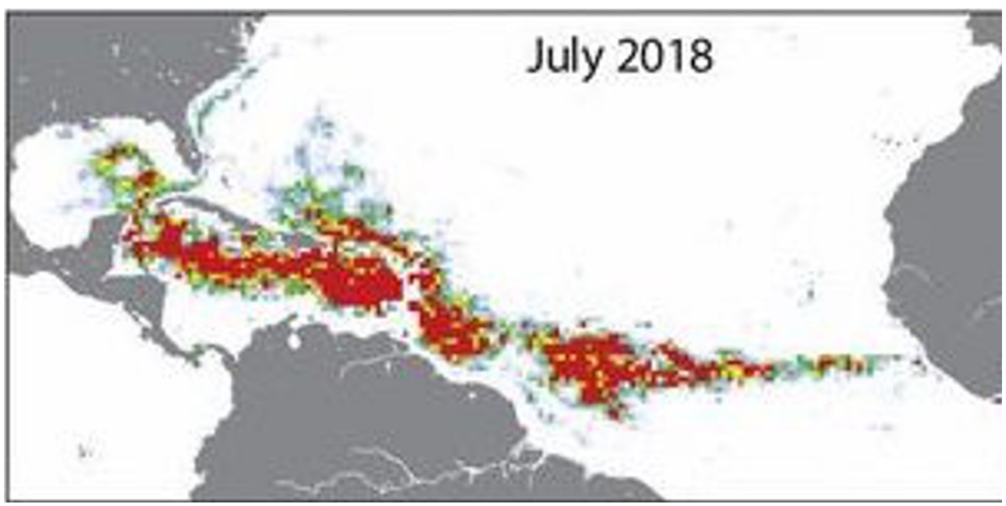


2018 chlorophyll-*a* concentrations (mg m^{-3})

Cyanobacteria bloom, Baltic Sea, 7/26/2019

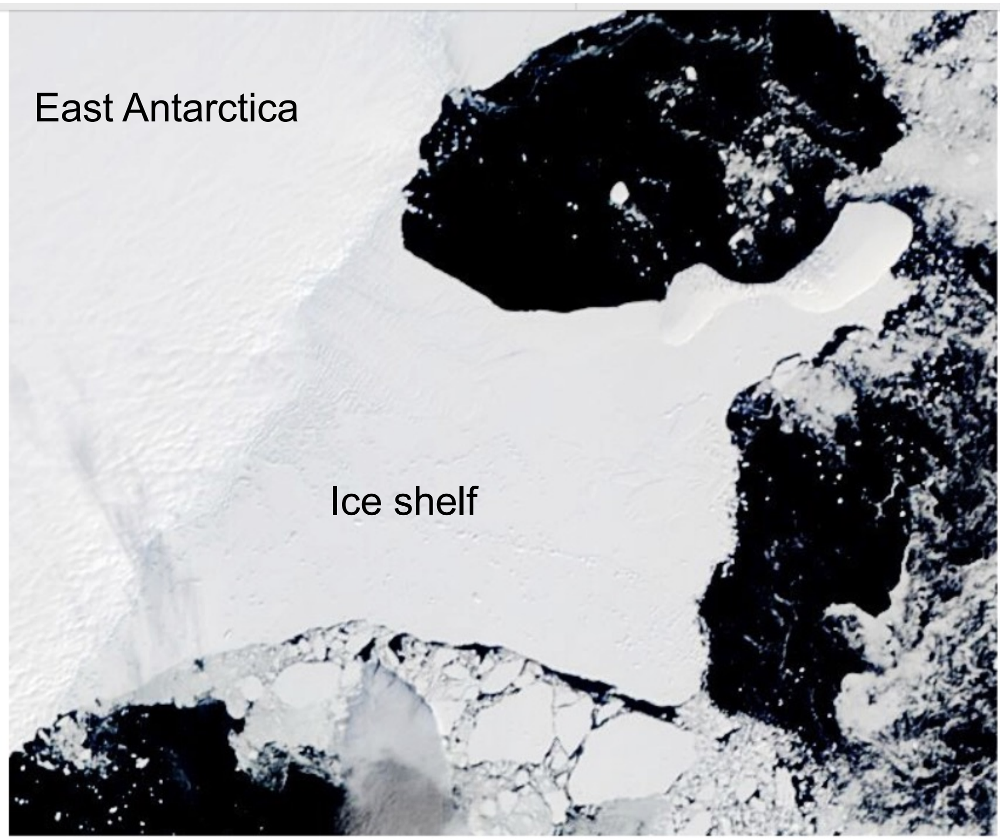
Deepwater Horizon oil spill, Gulf of Mexico, 4/25/2010



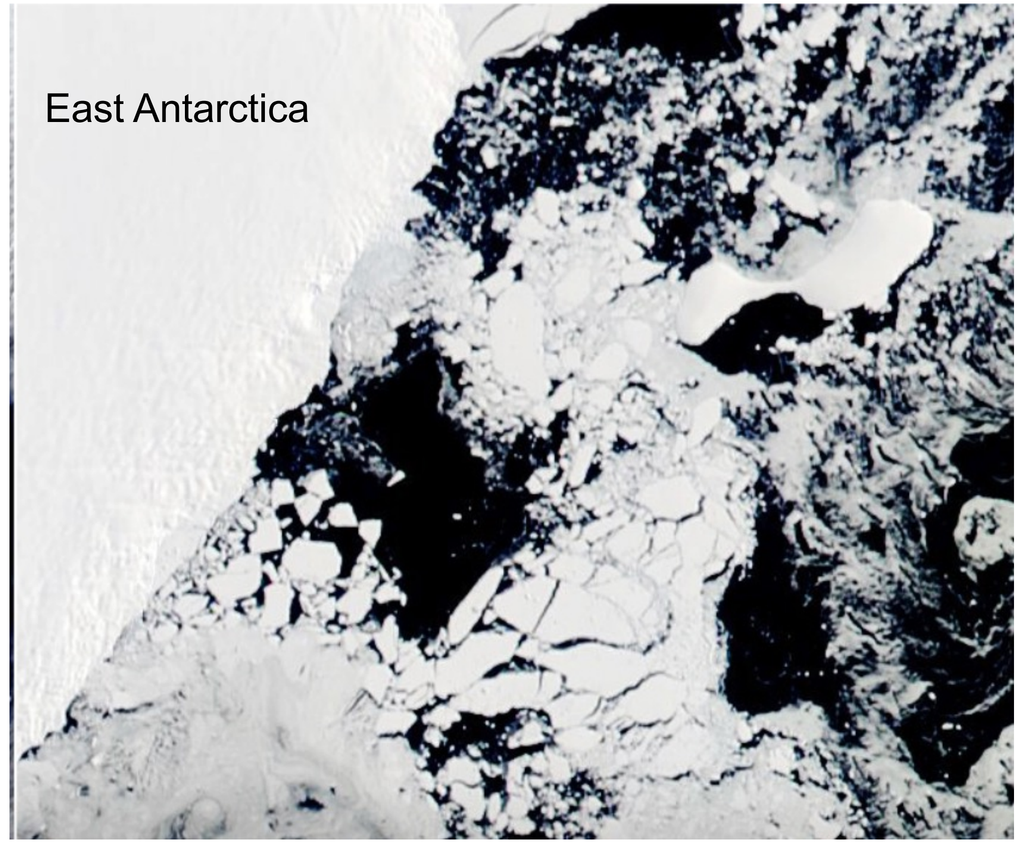


Great Sargassum Belt, July 2018 (from Wang et al. 2019)

Collapse of an East Antarctic Ice Shelf in March 2022, from MODIS Data



February 22, 2022



March 21, 2022

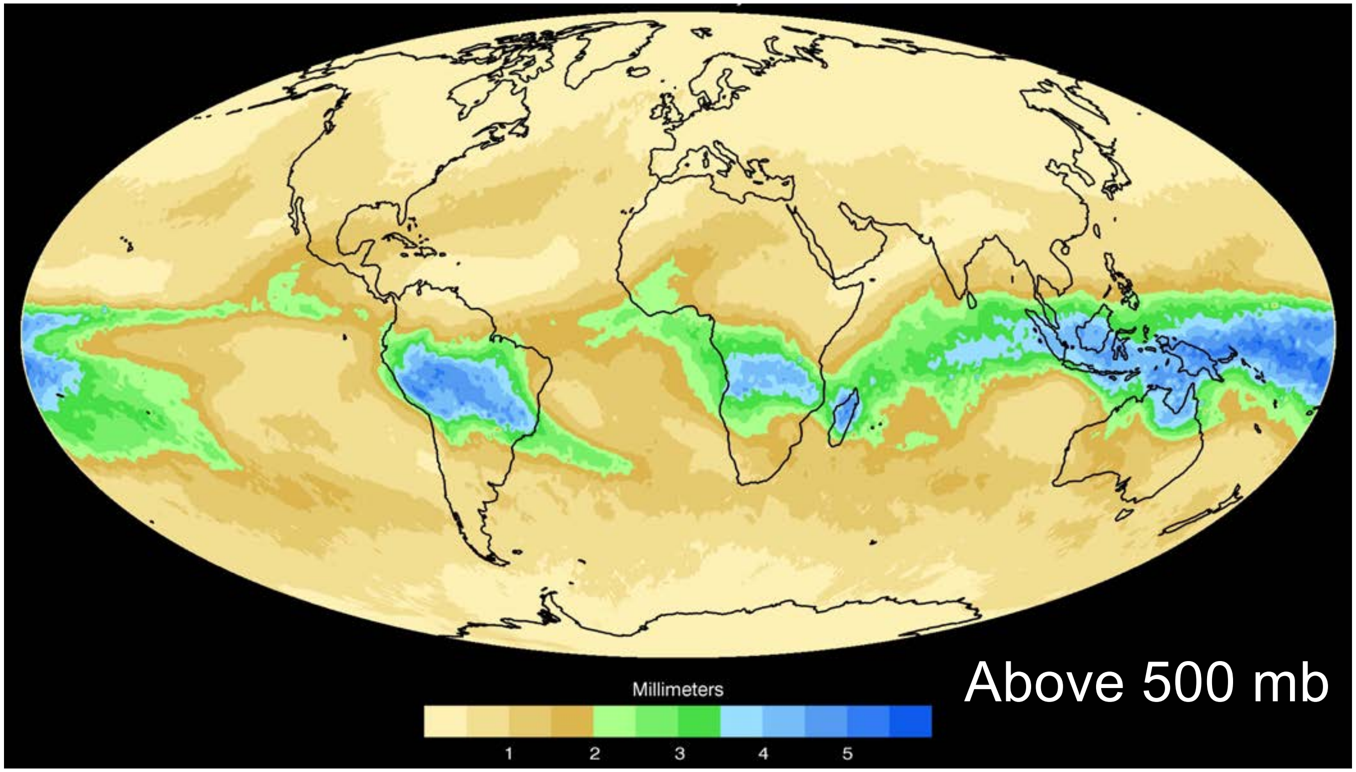
(images from https://earthobservatory.nasa.gov)

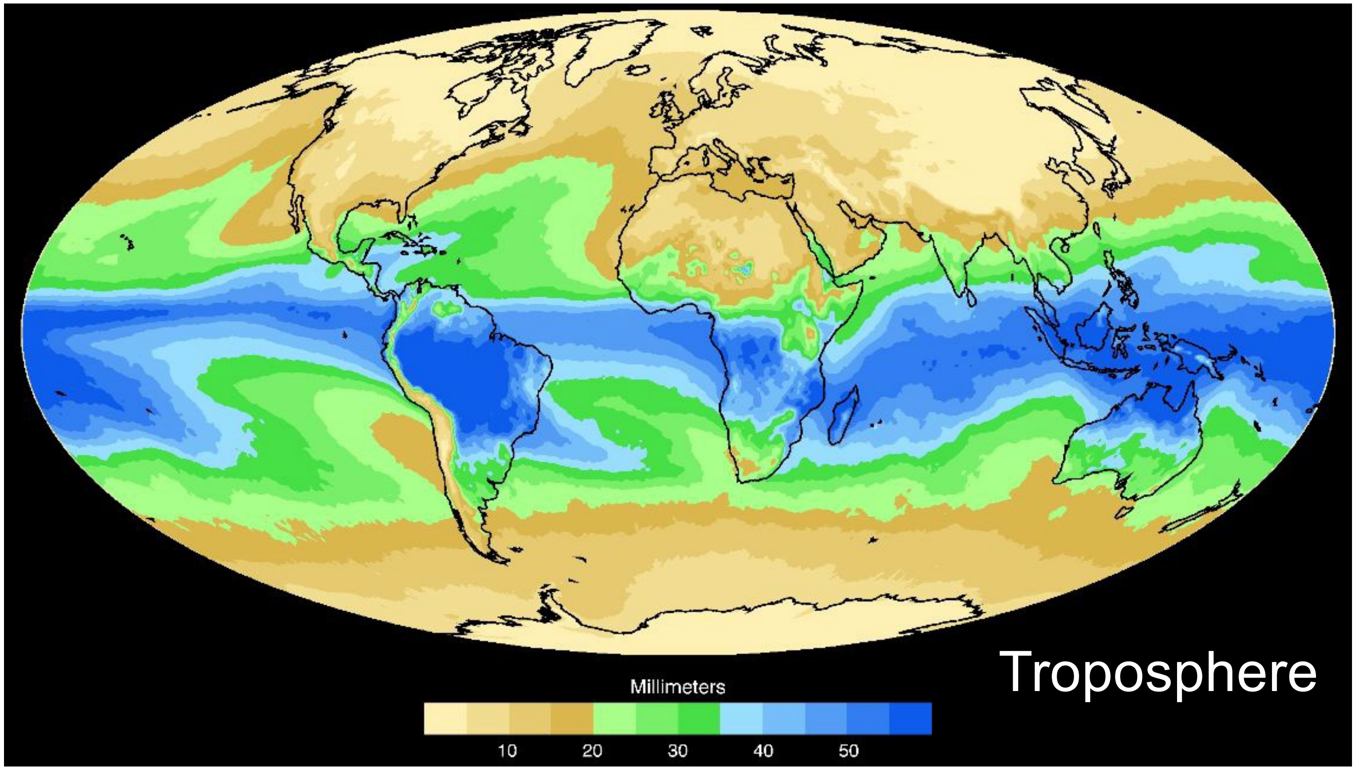
Sea Ice from AMSR-E Data

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

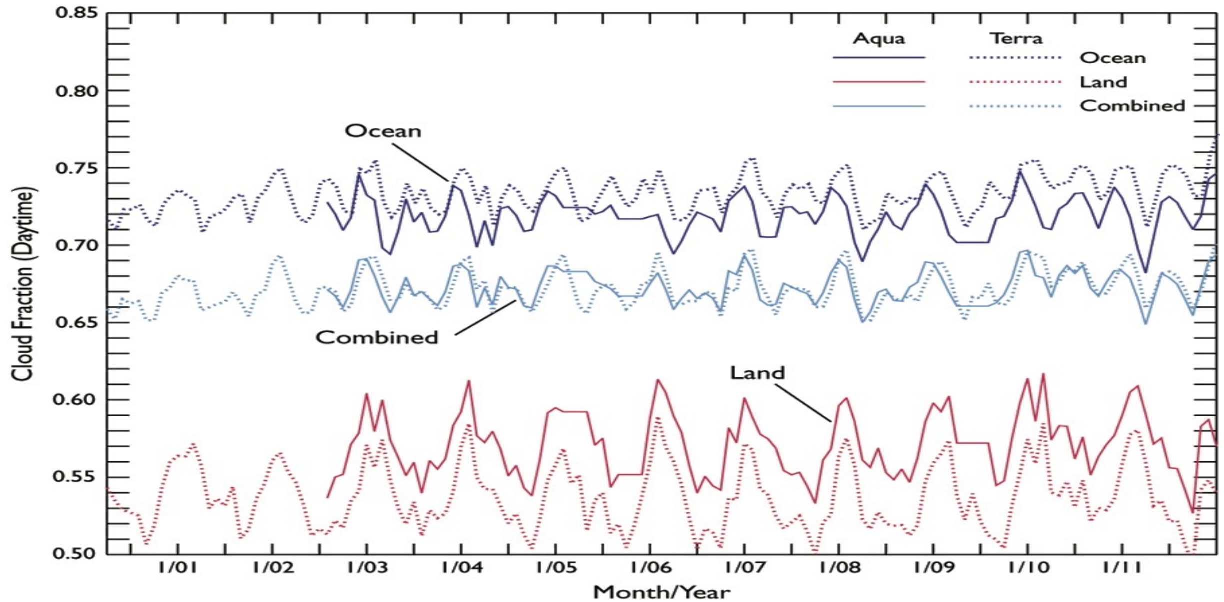




(images courtesy of C. Thompson and E. Olsen)

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

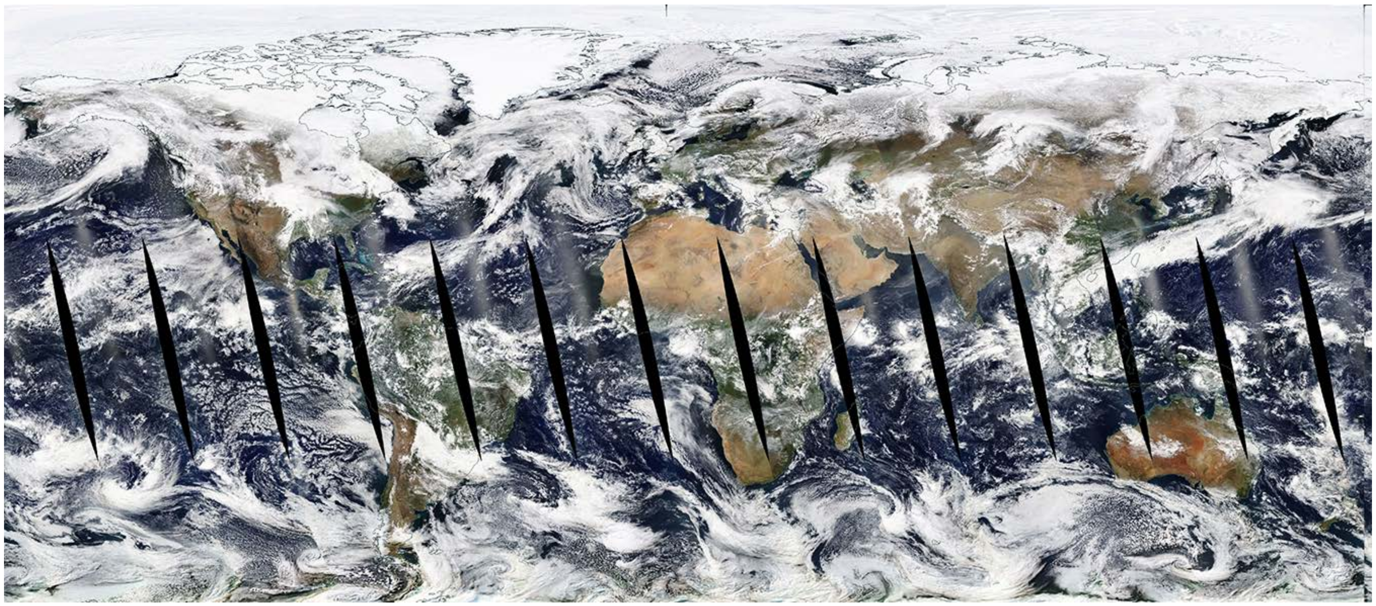
Cloud optical thickness

Cloud effective radius

Integrated water path

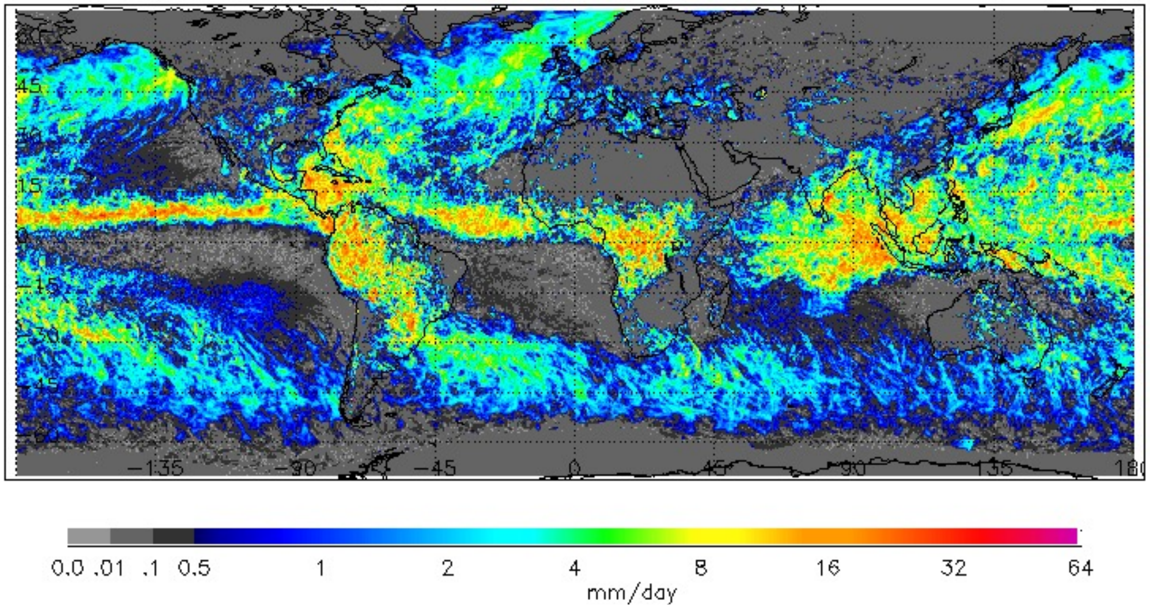
Fractional cloud cover

Global clouds, 5/2/22, from MODIS (from worldview.earthdata.nasa.gov)

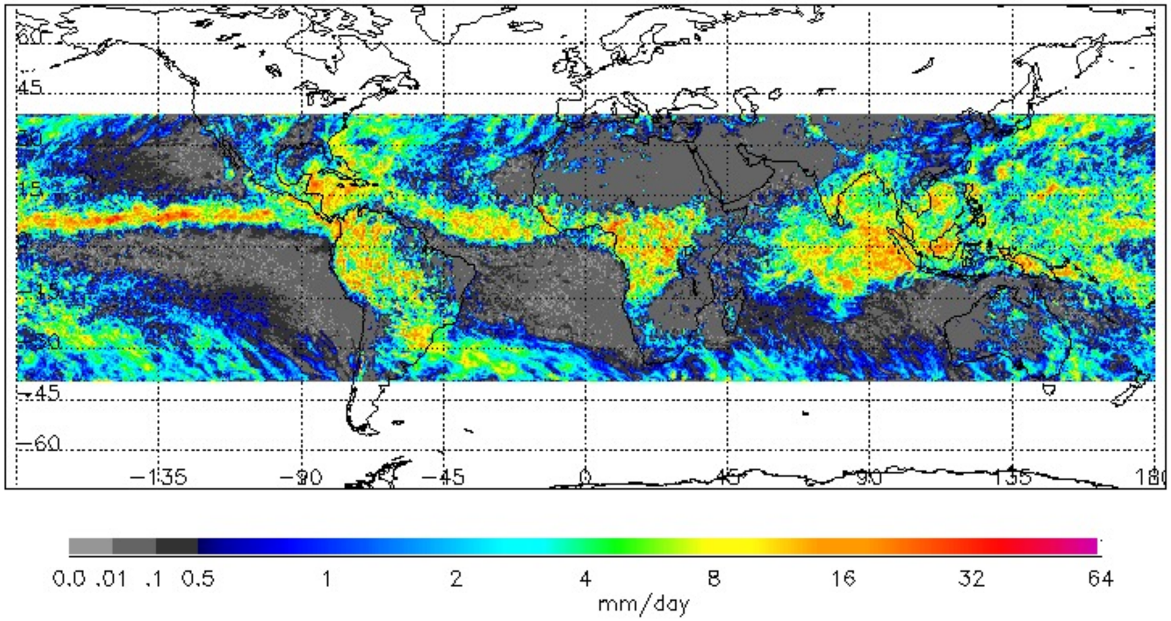


Global Rainfall Rates, from Aqua AMSR-E and TRMM Data

October 2005 Rainfall from AMSR-E data



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

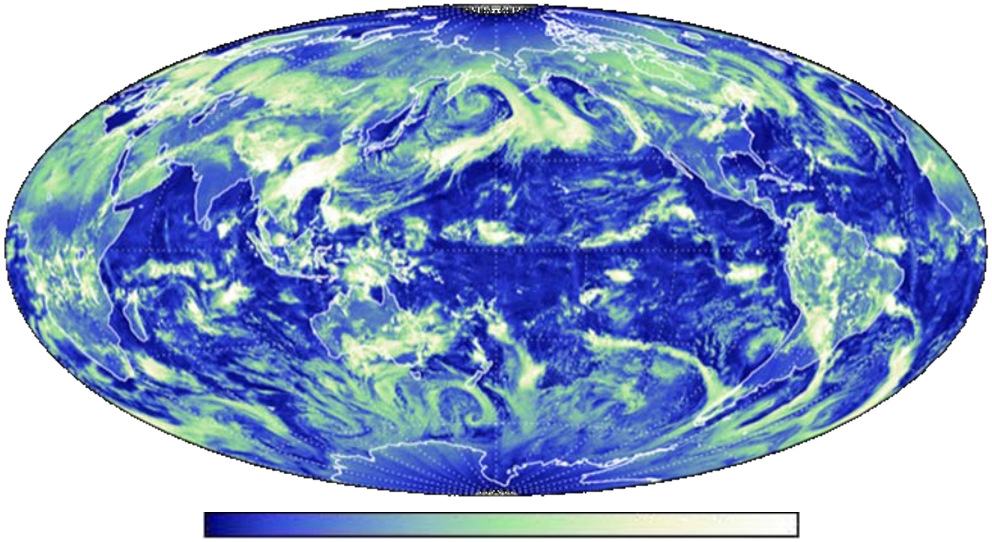


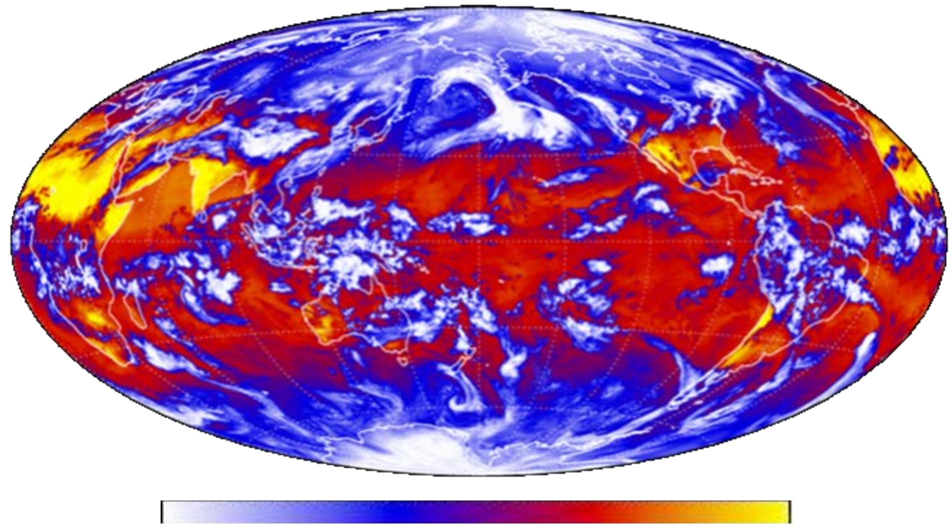
(images from Chris Kummerow and Ralph Ferraro)

Climate-Change Observations from Aqua

Outgoing Shortwave and Longwave Radiation at the Top of the Atmosphere (TOA), from CERES Data

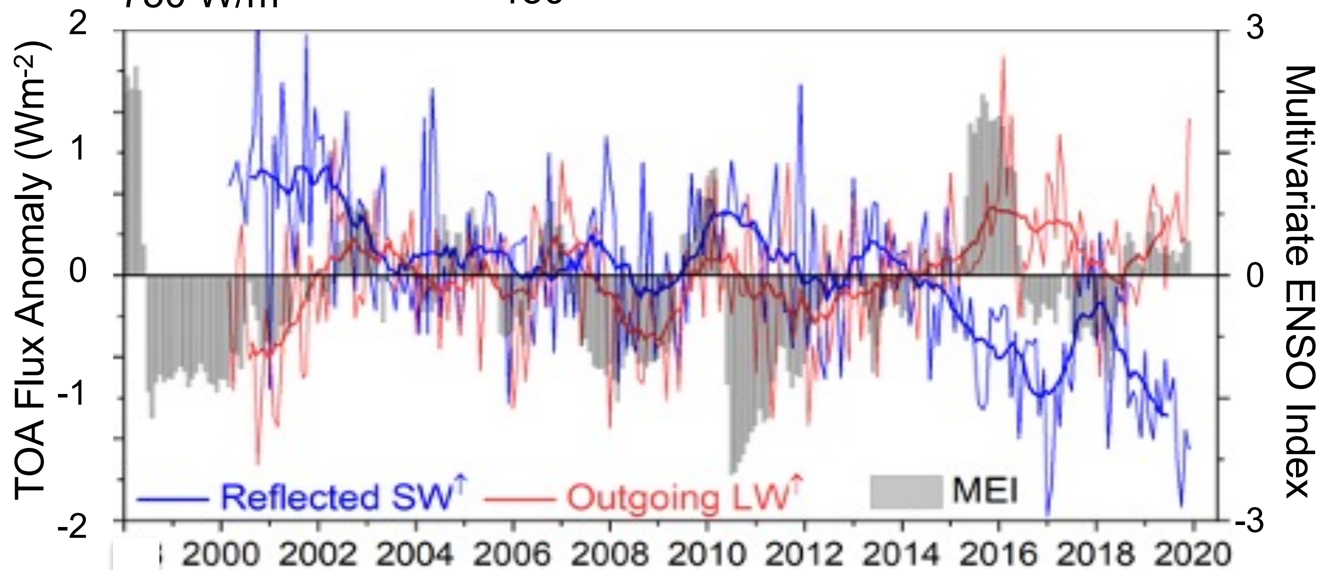
Reflected shortwave (left) and outgoing longwave (right) radiation, 3/18/11, from Aqua CERES data





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

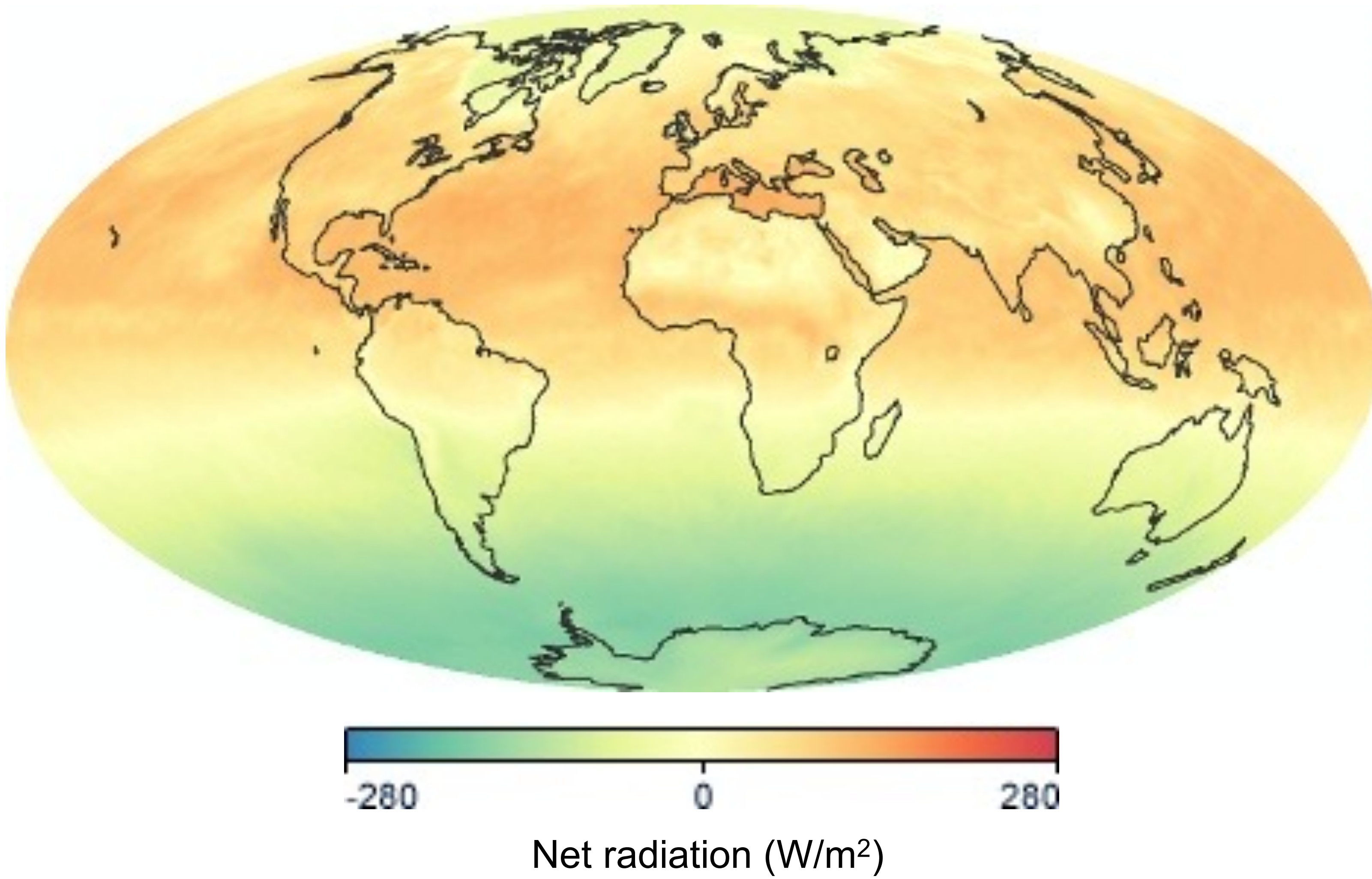
(Thin lines: monthly anomalies; thick lines: 12-month running means.)



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

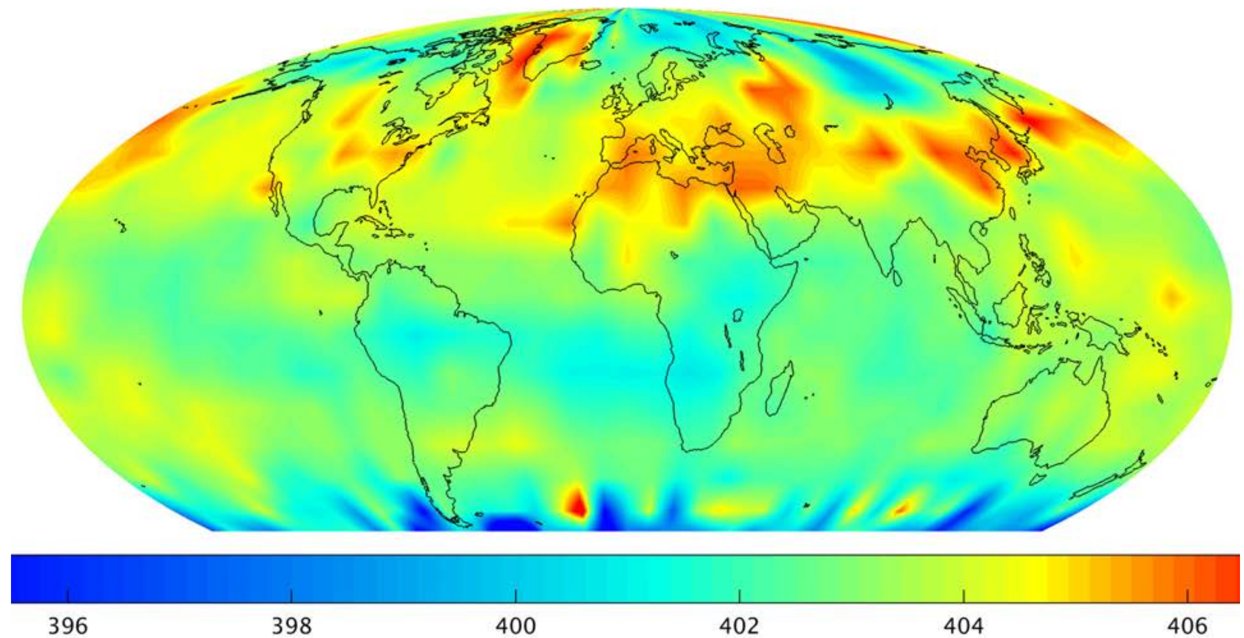


SORCE = Solar Radiation and Climate Experiment

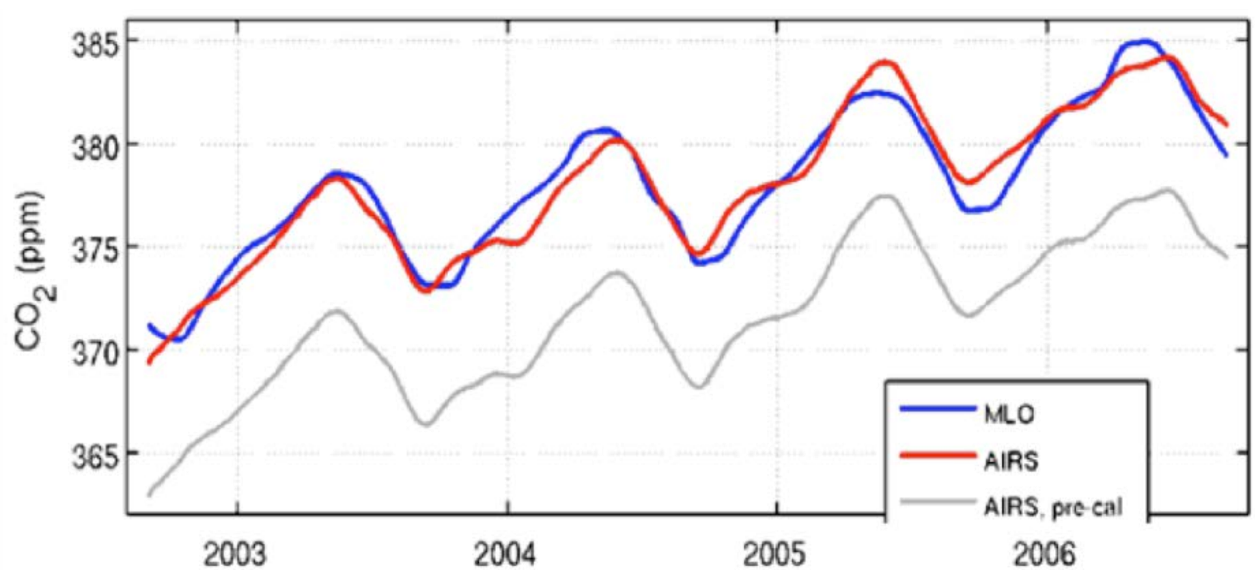
(from the CERES Science Team and earthobservatory.nasa.gov)

Mid-Troposphere CO_2 as derived from AIRS/AMSU Data

AIRS mid-troposphere CO_2 concentrations (ppm) for February 2017 (from Ed Olsen)

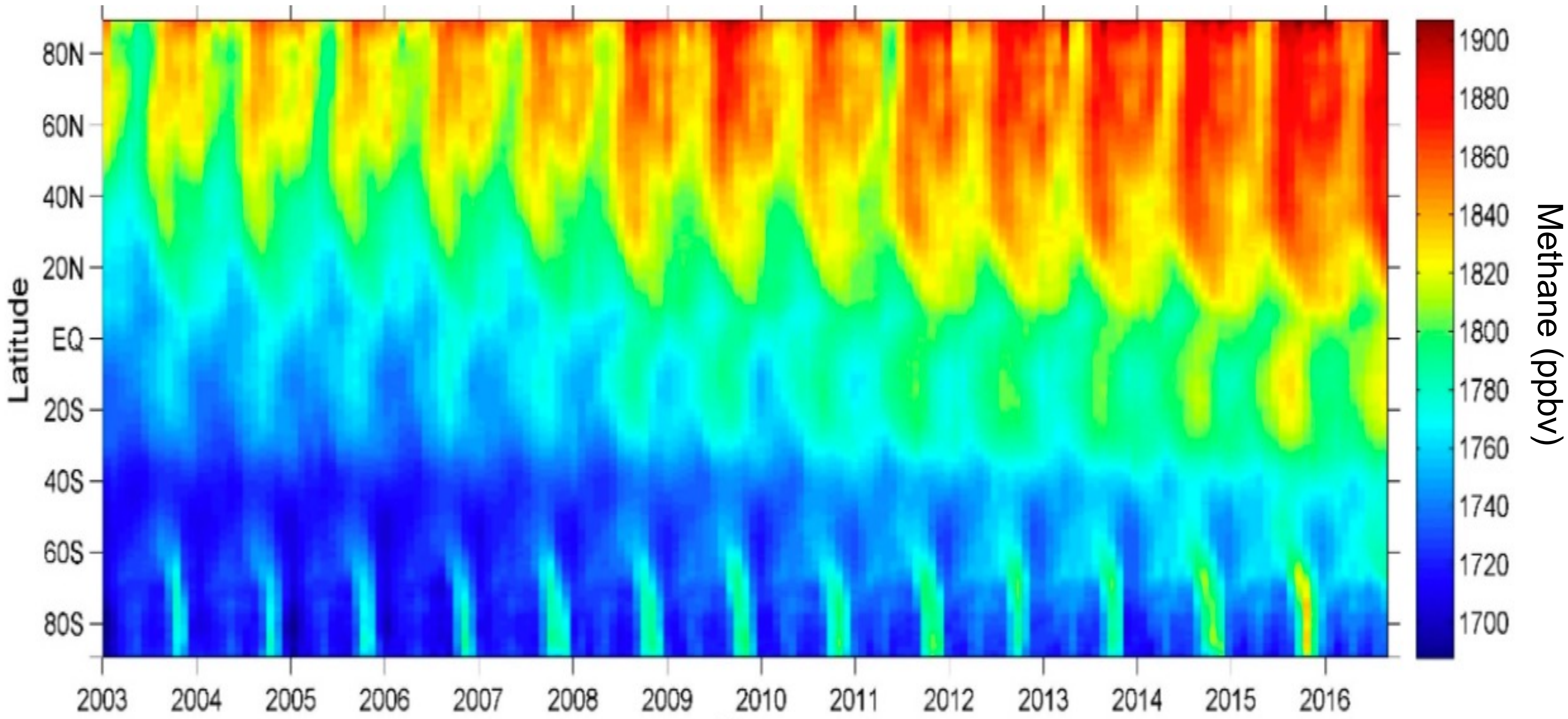


CO_2 time series from the Mauna Loa Observatory (MLO) and from AIRS retrievals for the Pacific Ocean before and after calibration (from Strow and Hannon 2008)



[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.]

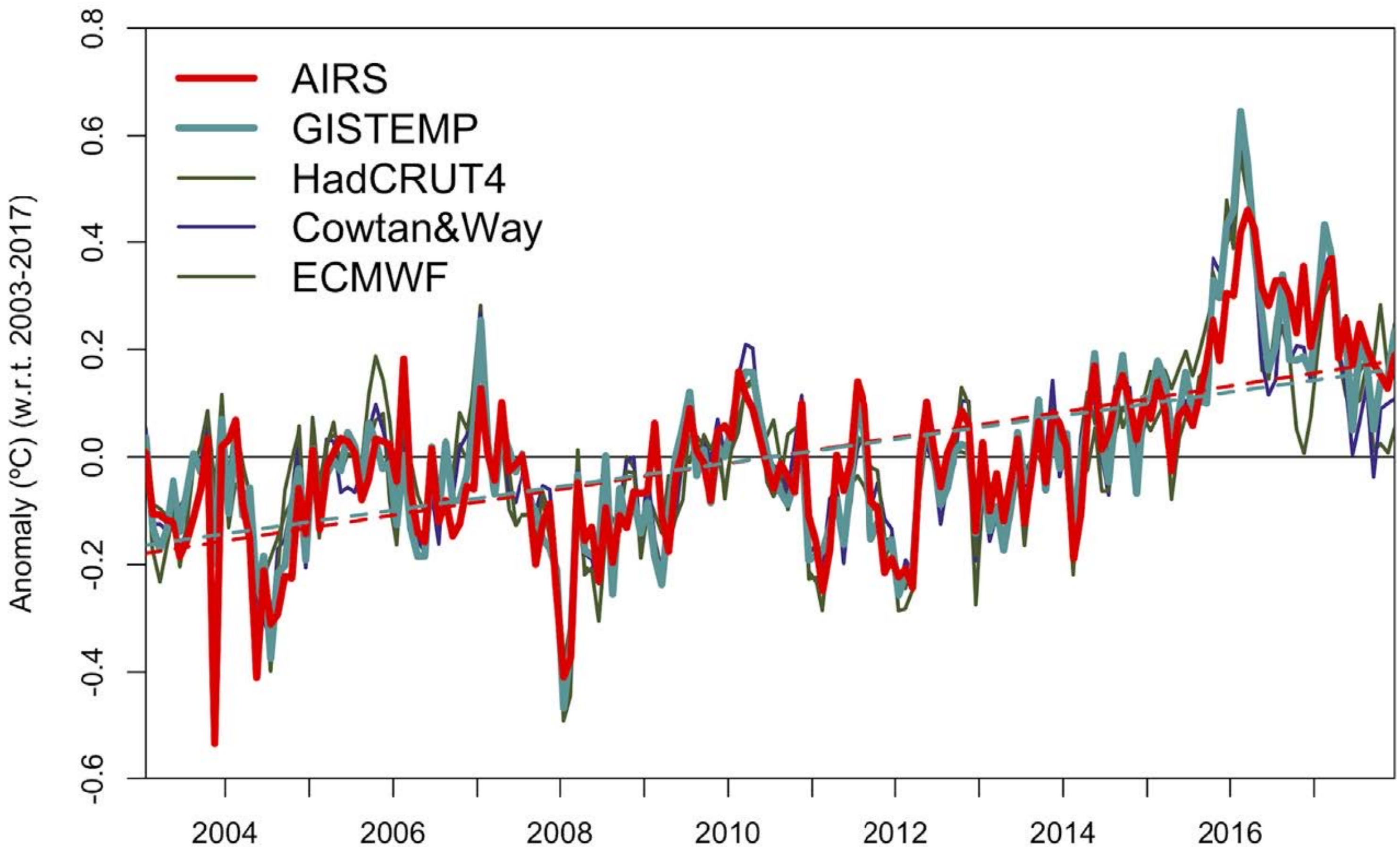
Zonal Tropospheric Methane (CH_4), 2003-2016, as derived from AIRS Data



(from Zou *et al*. 2019)

Global Warming from AIRS Data

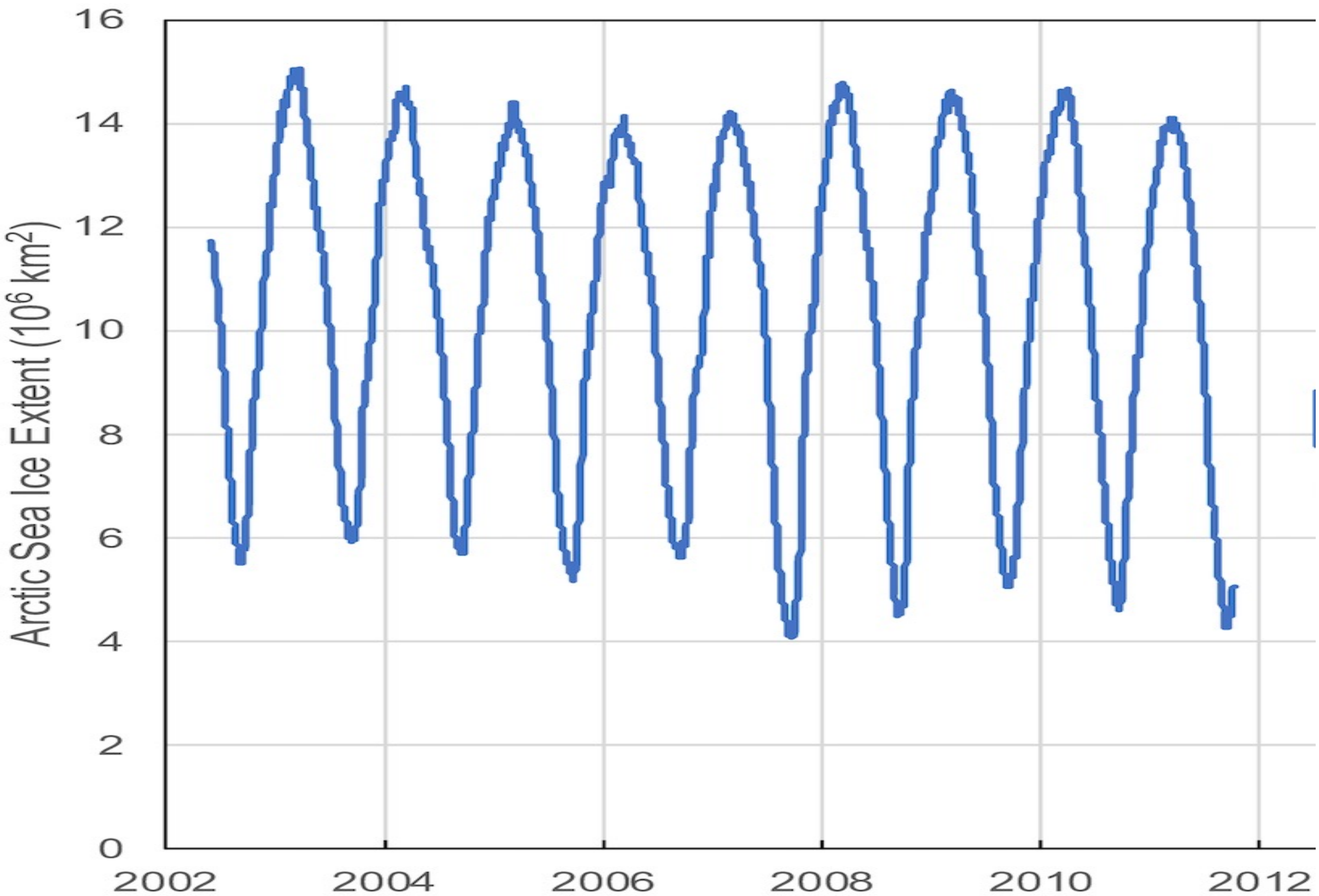
Global monthly mean surface temperature anomalies, 1/2003 – 12/2017, from AIRS data and four in situ data sets



(from Susskind *et al.* 2019)

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.

Arctic Sea Ice Extents, 2002-2011, from AMSR-E Data

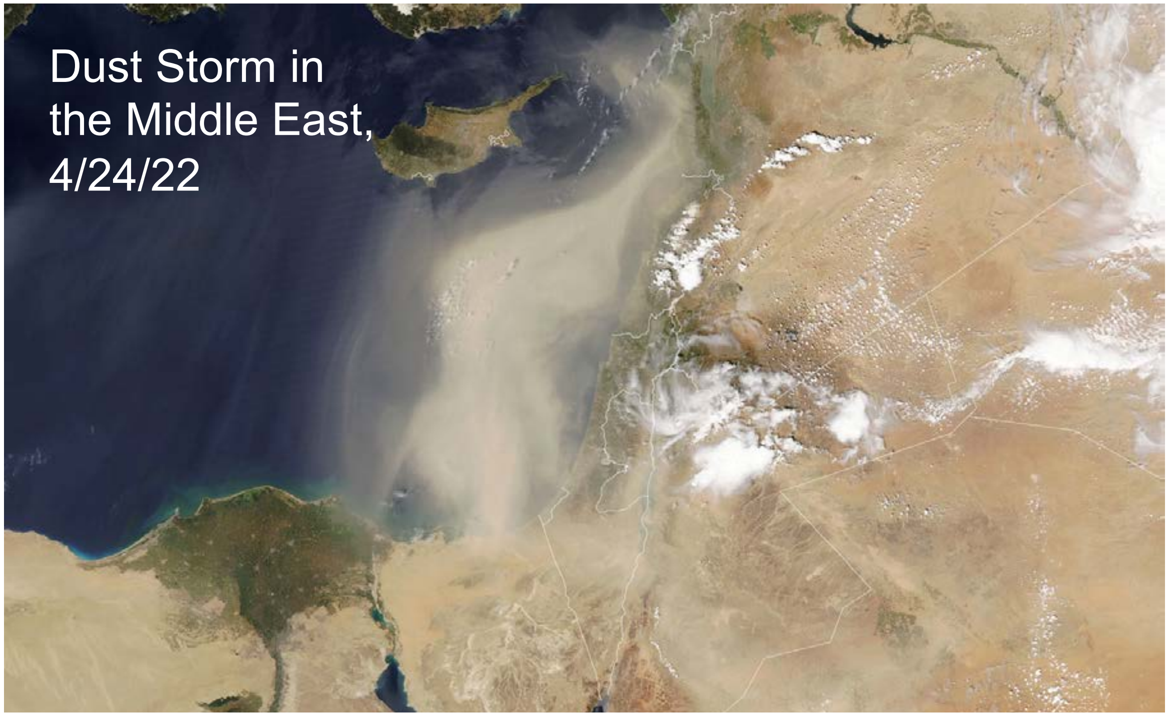


(data from JAXA; plot from W. Meier)

Air-Quality Observations from Aqua

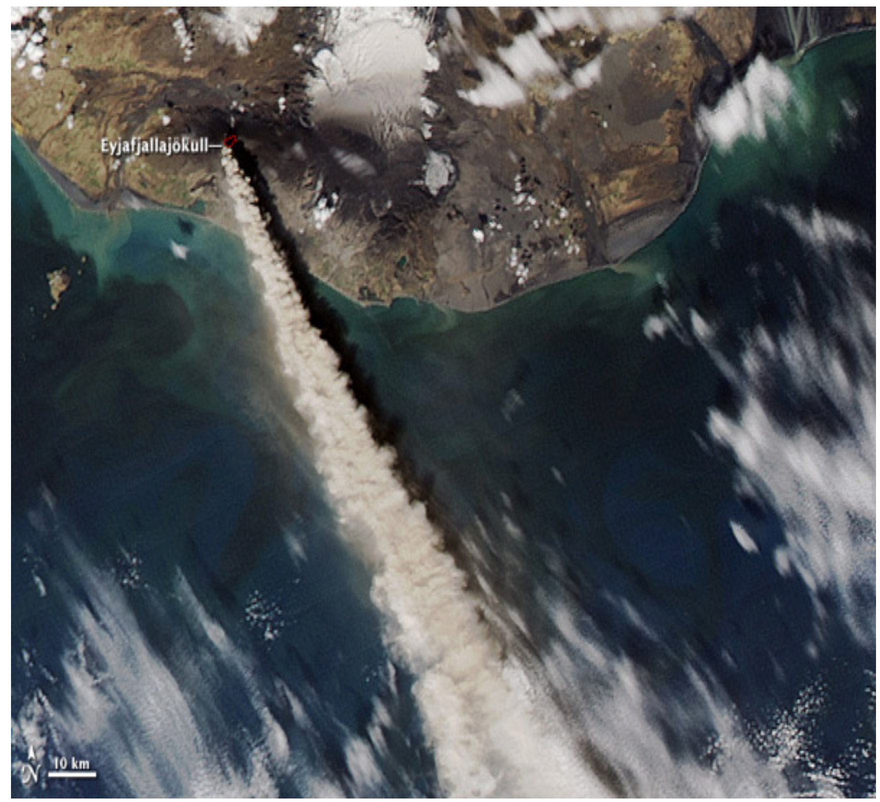
(photo from ImageVortex.com)

Sample Visible Air Quality Issues Seen in Aqua MODIS Imagery

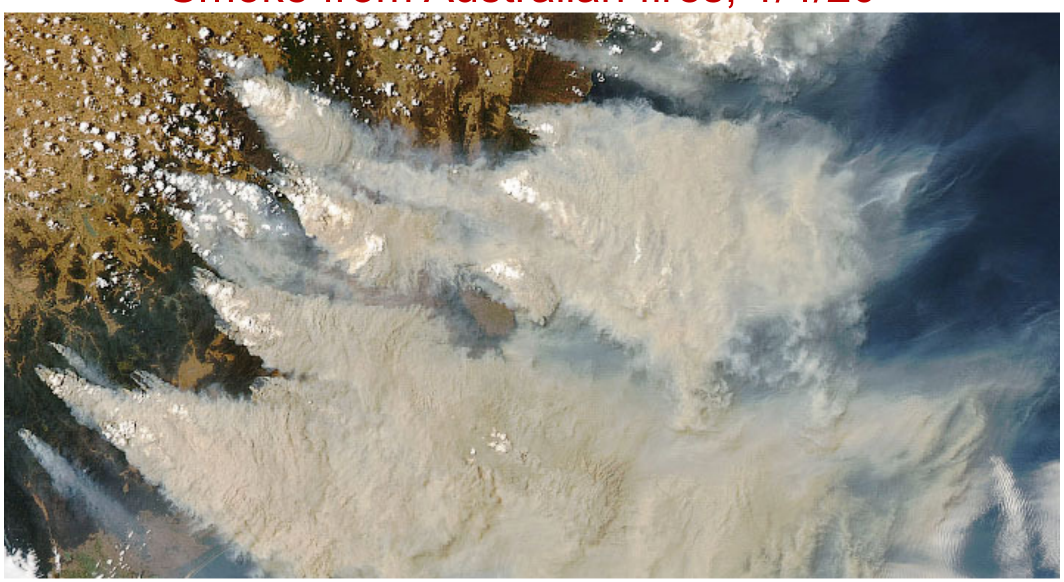

Dust Storm in the Middle East, 4/24/22

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

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

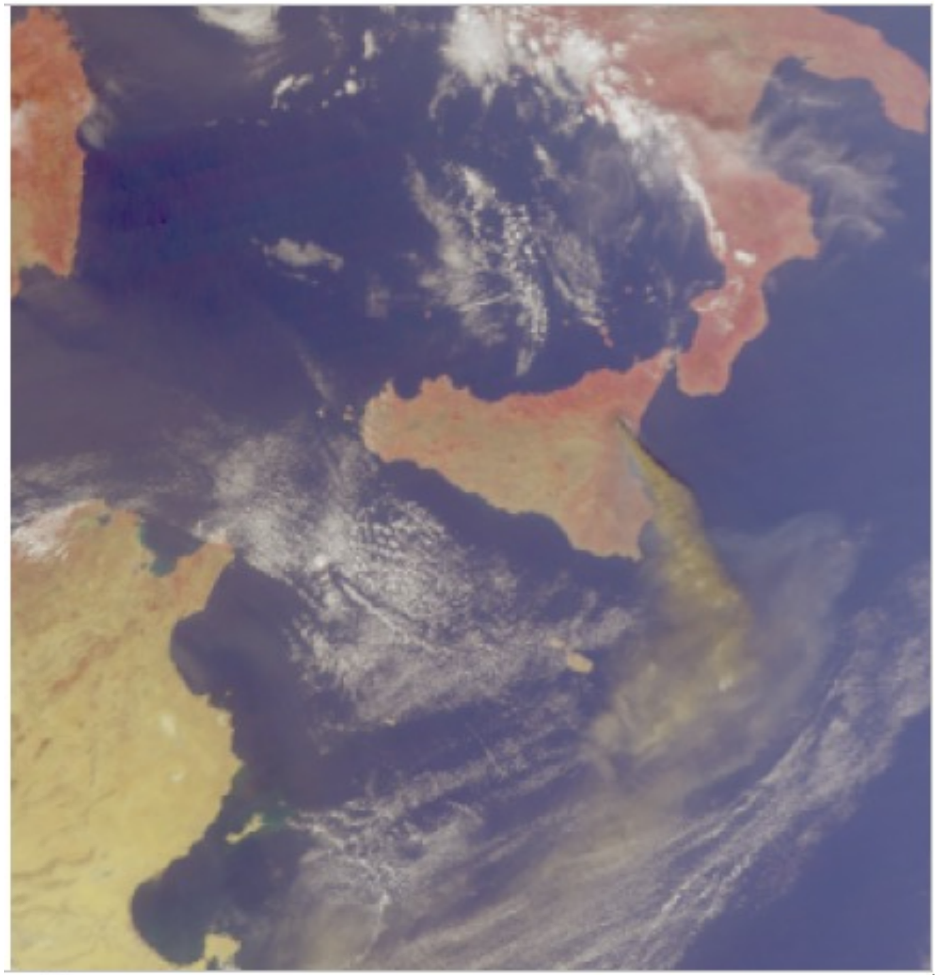


Smoke from Australian fires, 1/4/20

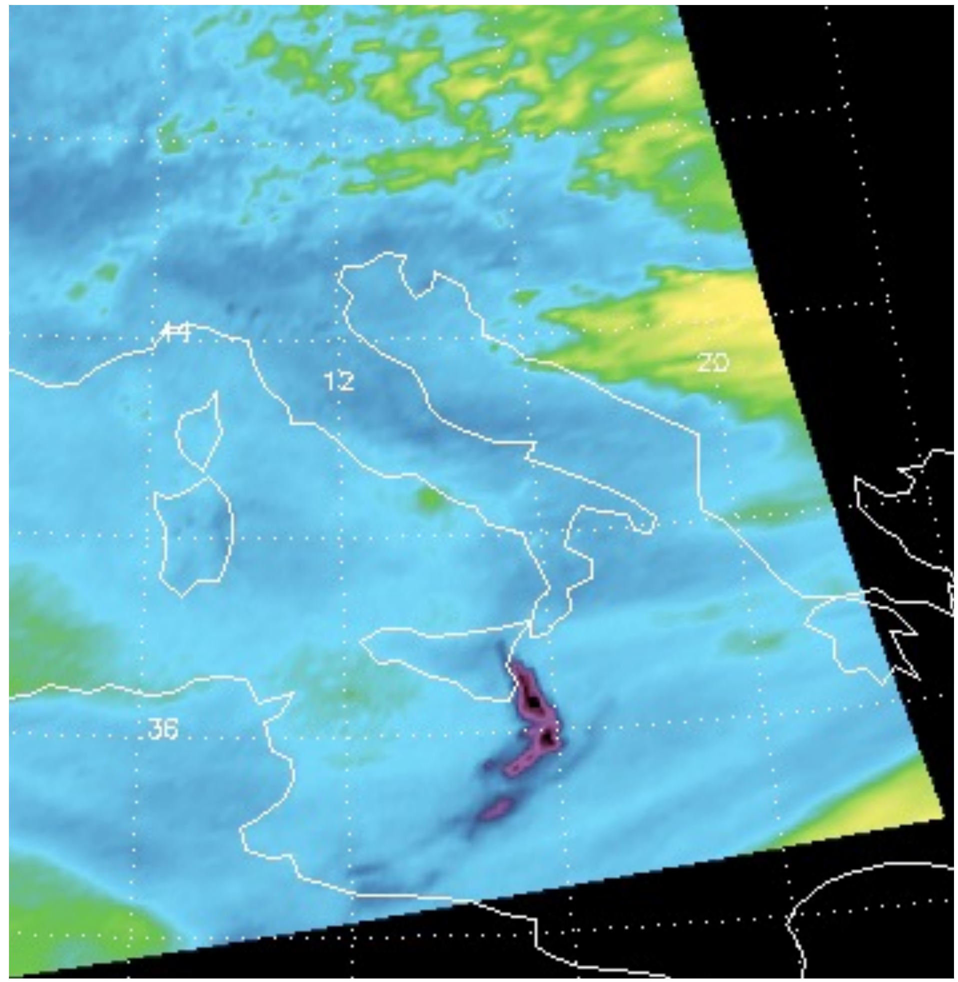


Mt. Etna Eruption, October 28, 2002, from AIRS Data

Visible/Near IR image



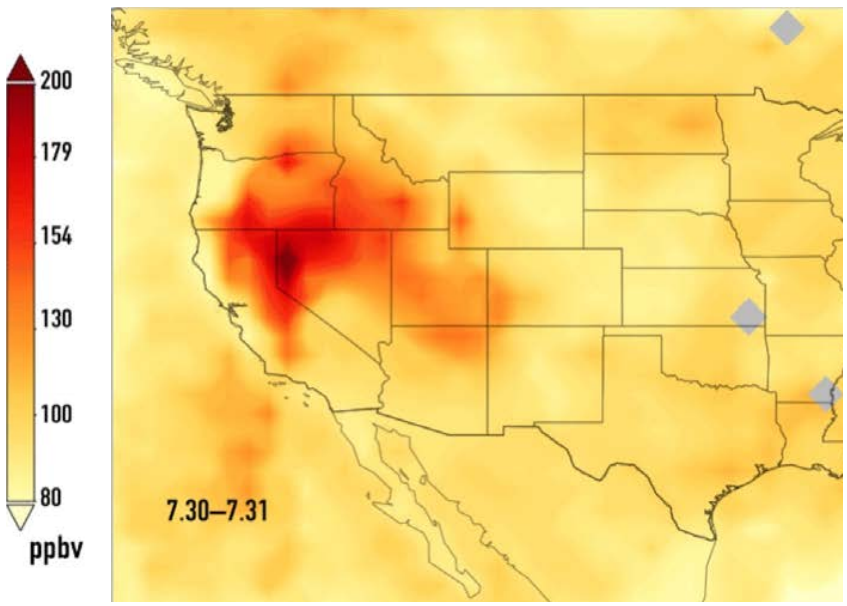
IR difference image highlighting SO_2

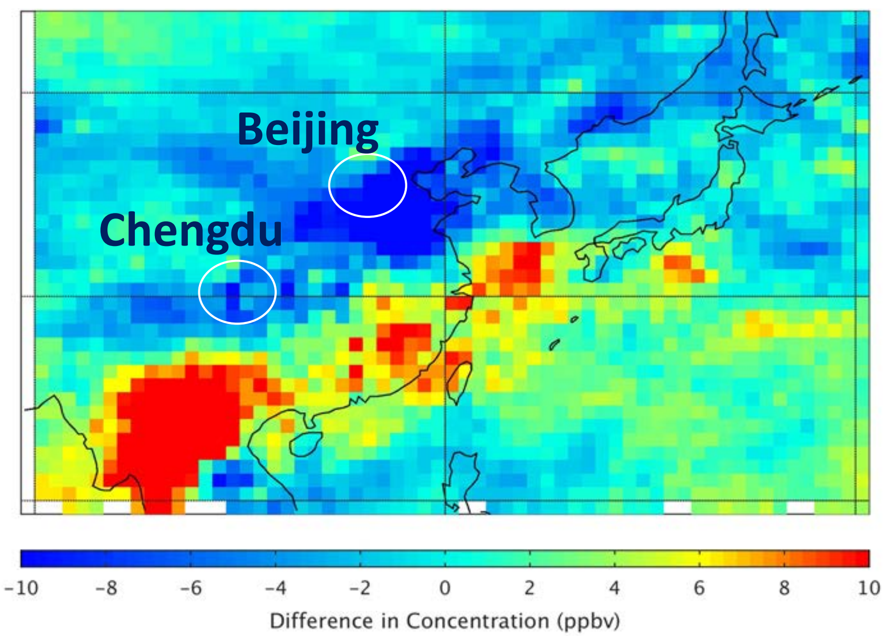


(images courtesy of M. Chahine and the AIRS Science Team)

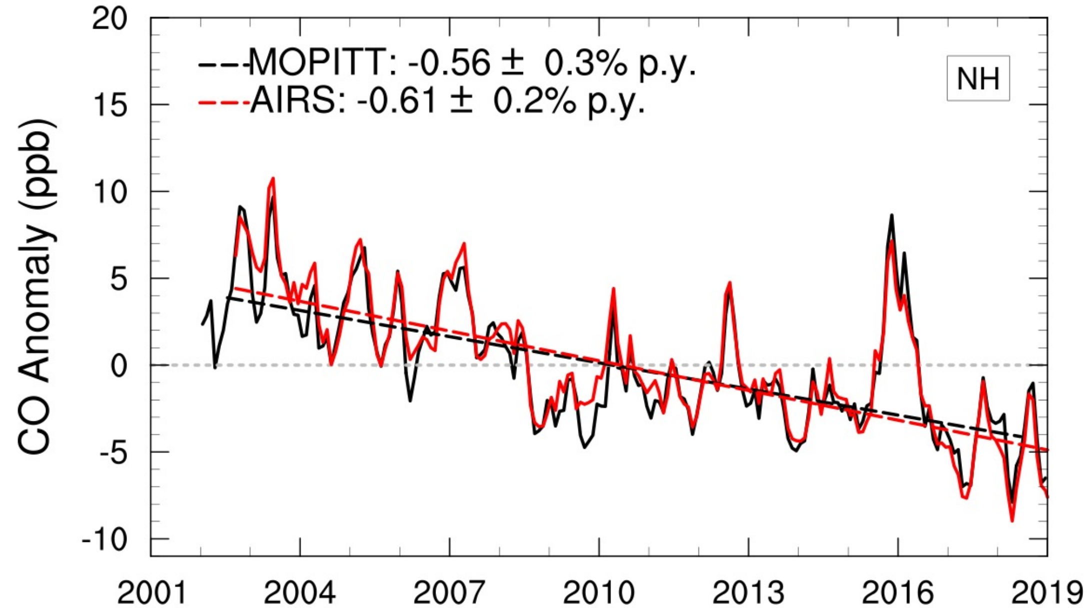
Atmospheric Carbon Monoxide (CO) from AIRS Data

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





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

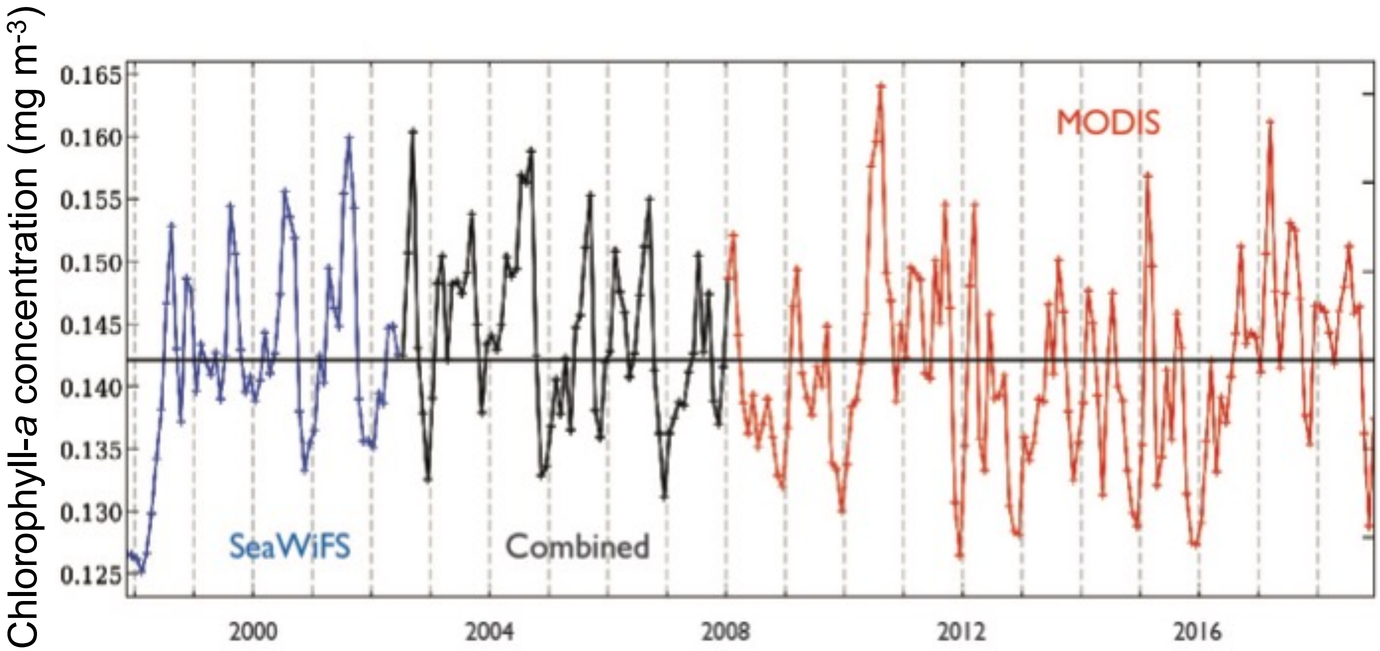


(from Rebecca Buchholz, based on Buchholz *et al*. 2021)

MOPITT = Measurements of Pollution in the Troposphere (on Terra)
ppb = parts per billion
ppbv = parts per billion by volume
p.y. = per year

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

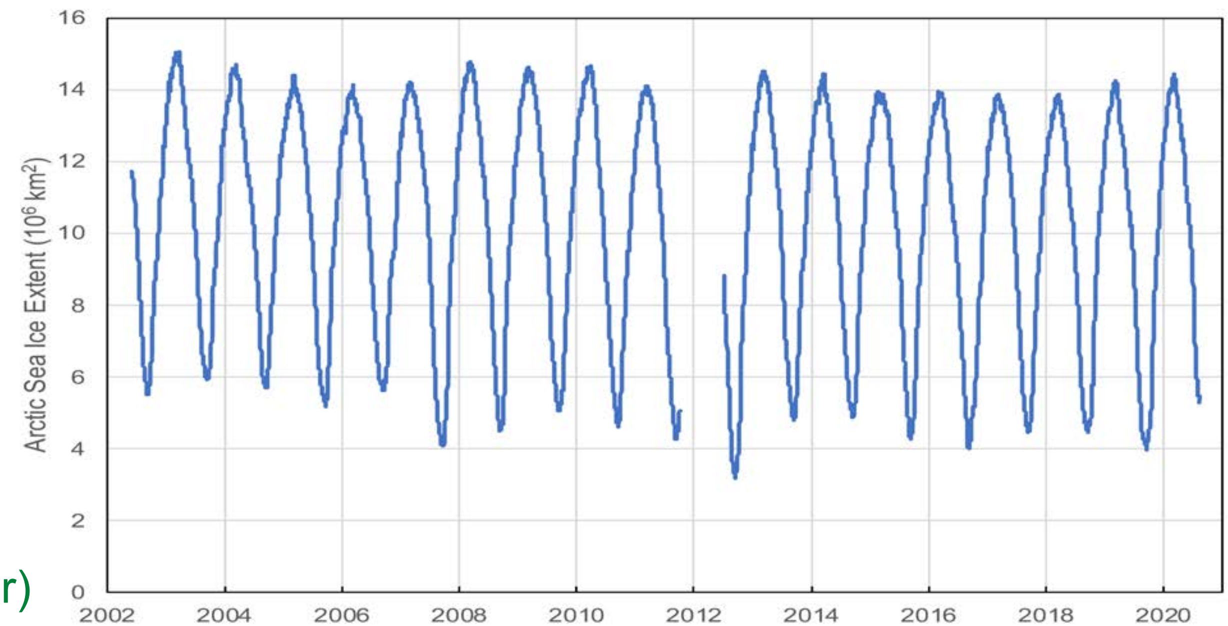
Use of Aqua Data to Extend and be Extended by Other Satellite Data Sets



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

(from Franz *et al*. 2019)

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

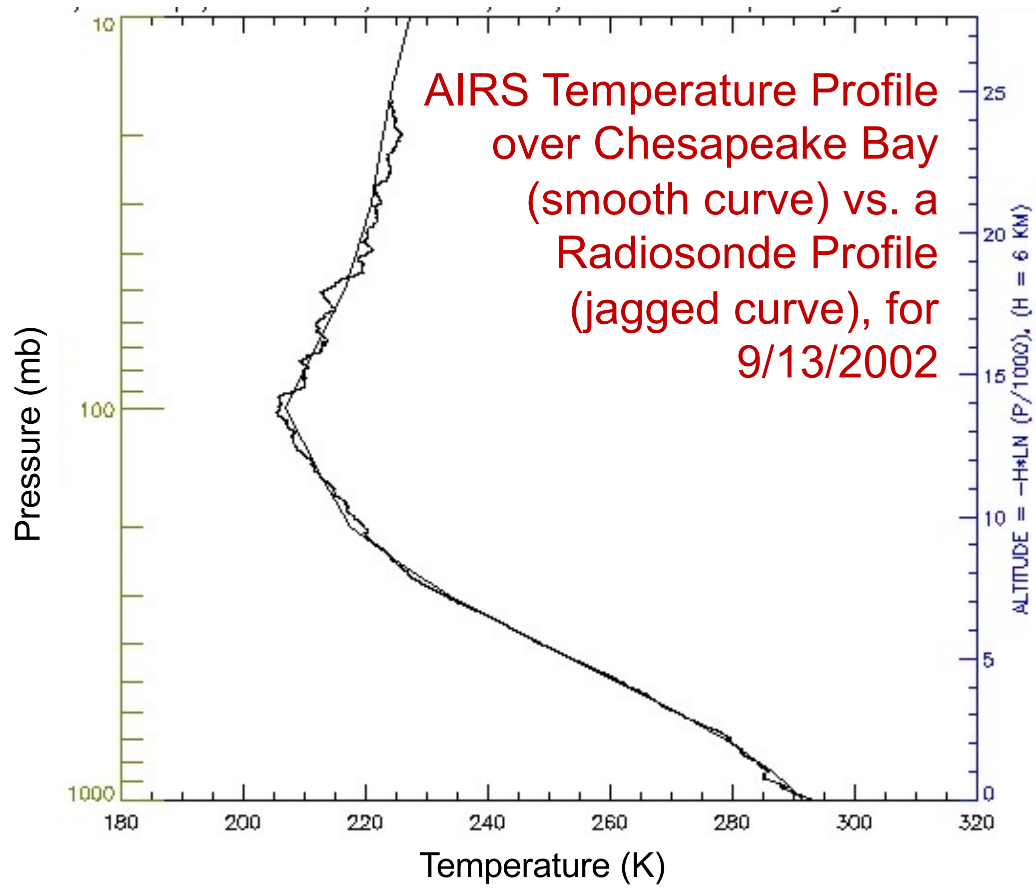


(data from JAXA; plot from W. Meier)

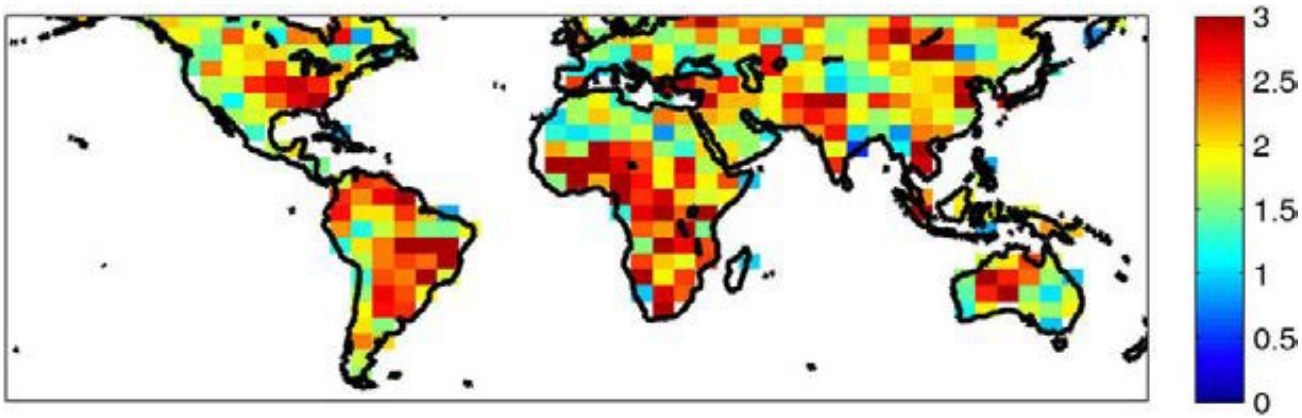
Uses of Aqua Data Beyond Science

Use of AIRS Data in Weather Forecasting

"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.



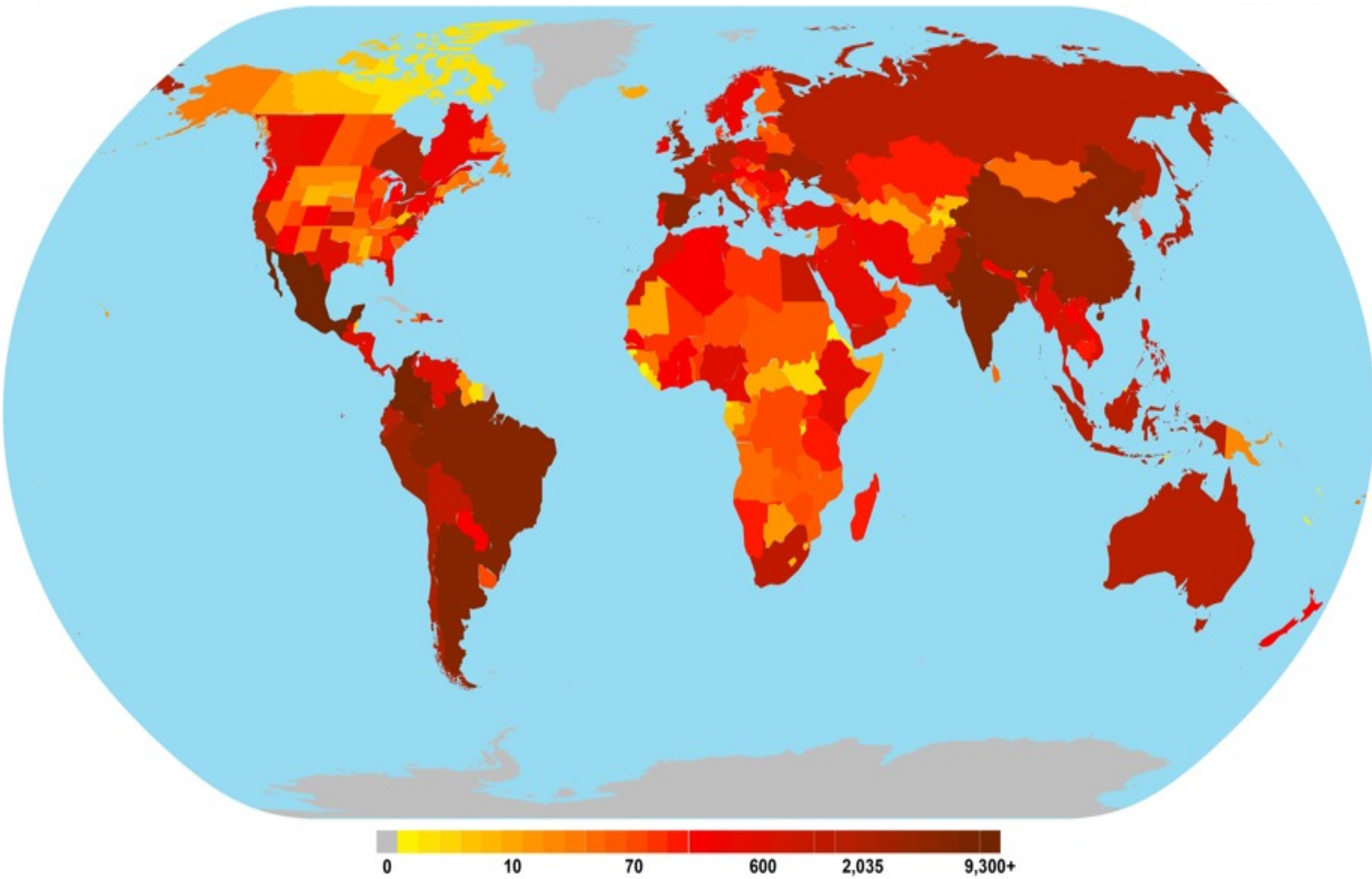
Improved mean lead time (in months) for early drought detection through incorporating AIRS relative humidity data



(plot from Wallace McMillan; map from the AIRS Science Team; titles added)

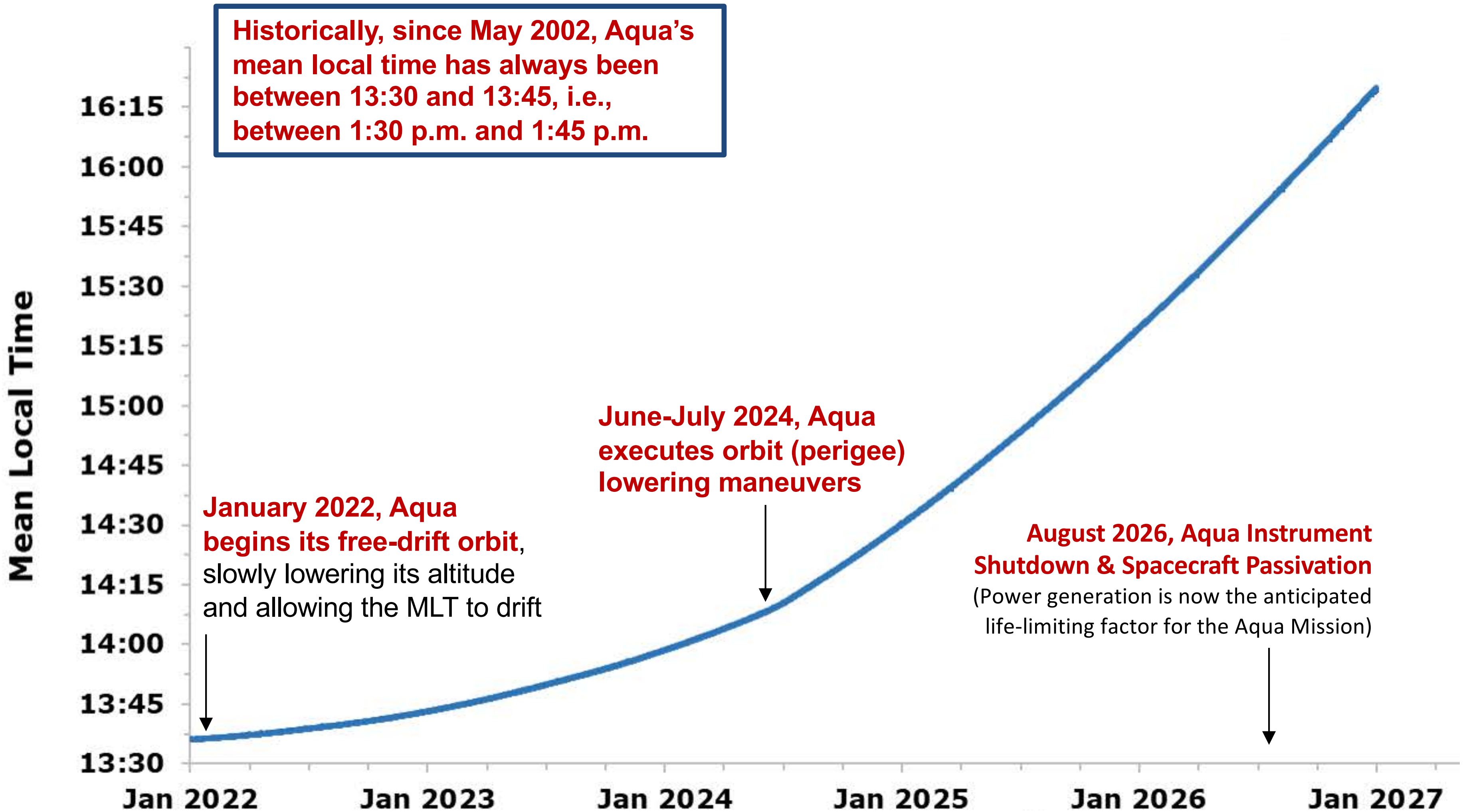
Federal Government Users of Aqua Data

Number of Users of CERES FLASHFlux Data Products, 5/16/18 – 11/30/19



FLASHFlux = Fast Longwave and Shortwave Radiative Flux

Projected Mean Local Time at Northward Equatorial Crossings
(assuming mission funding at requested levels)



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.