



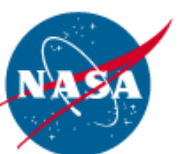
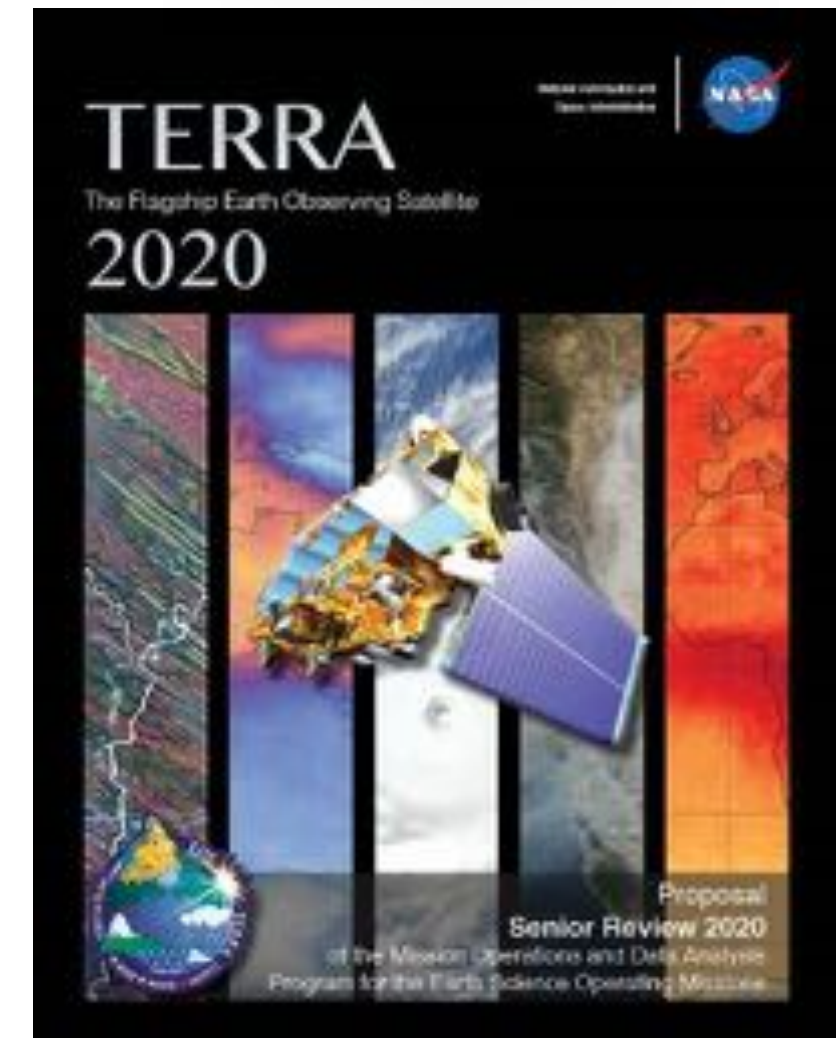
Status of the Terra Mission

Kurt Thome, Robert Wolfe, Si-Chee Tsay,

MODIS/VIIRS Science Team Meeting
November 19, 2020

Terra Mission Summary

- Terra 20-Year Anniversary celebrated last December
- Successful Mission Extension Senior Review Proposal in 2020
 - Funds to operate Terra through end of FY23
 - Requested to submit a 2023 Senior Review Proposal
- 2020 Spring Inclination Adjust Maneuvers
 - Last of these maneuvers
 - Terra is drifting in equator crossing time
 - Terra is maintaining altitude
- Terra continues to operate well
 - Reliability estimates show no expected issues thru 2025+
 - Will turn 21 on December 18
- Anomaly affecting onboard data storage is impacting MODIS operations



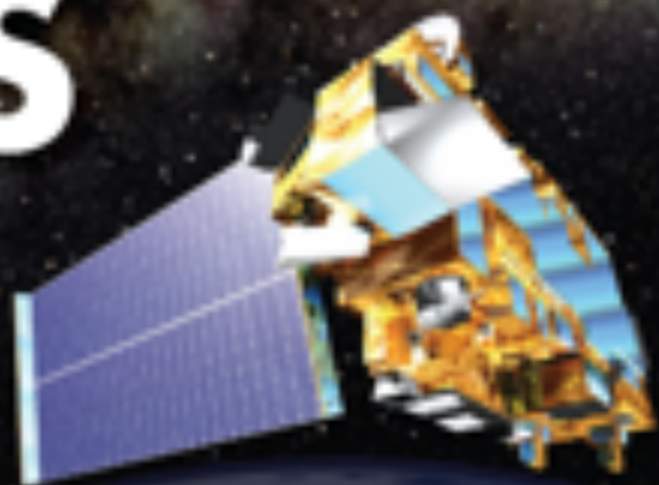
TERRA



20 YEARS

5 INSTRUMENTS
ASTER • CERES • MISR
MODIS • MOPITT

OVER
100,000
ORBITS



20,000 PUBLICATIONS
350,000 CITATIONS

**4.6
MILLION
USERS**

**83 DATA
PRODUCTS**

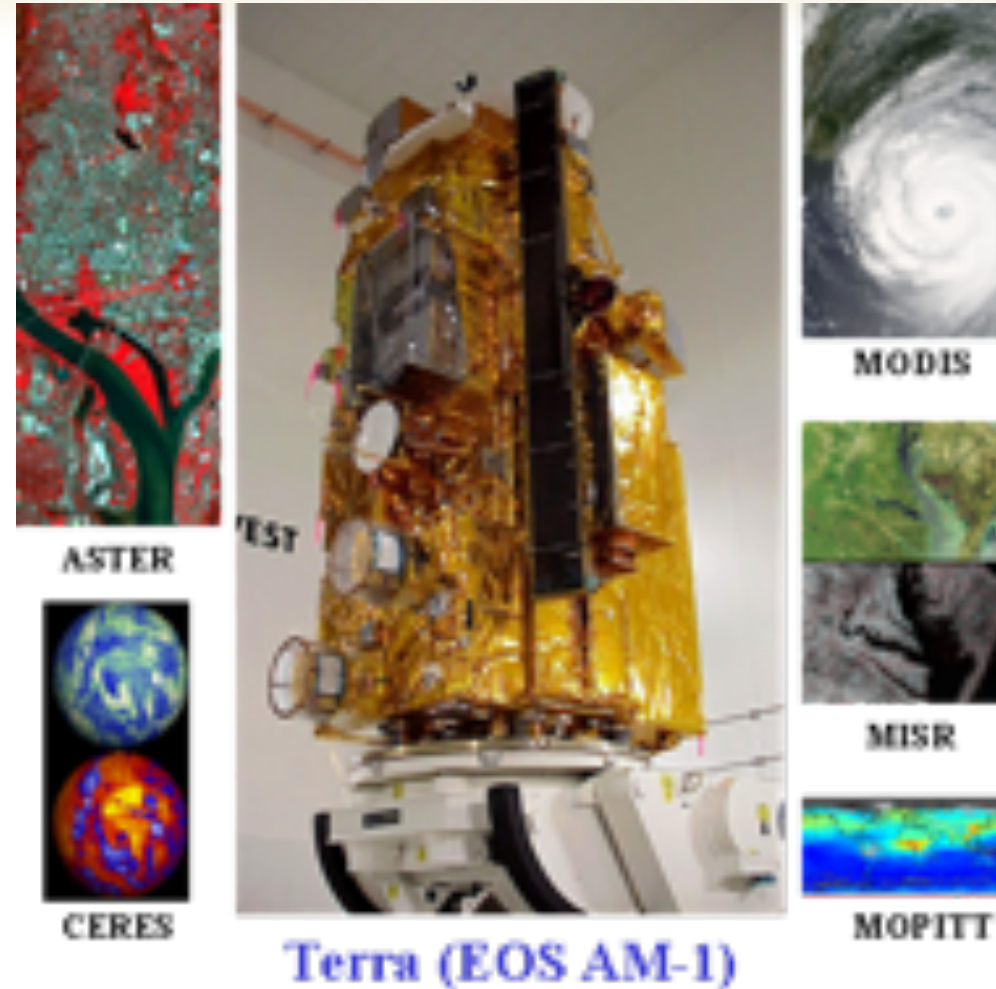
Terra team and sensors

- (GSFC)

Project Scientist (PS)	Kurt Thome
Deputy PS	Si-Chee Tsay
Deputy PS for Data	Robert Wolfe
ESMO Project Manager	Wynn Watson

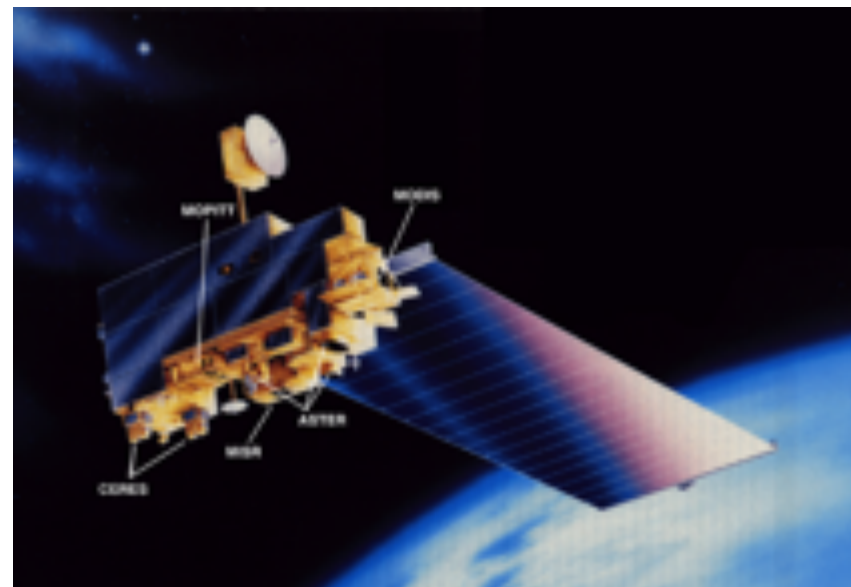
- Instrument PIs & Team Leaders (T.L.)

ASTER	Japan TL US TL	Yasushi Yamaguchi Michael Abrams (JPL)
CERES	PI	Norman Loeb (LaRC)
MISR	PI	David Diner (JPL)
MODIS	TL	Michael King (UC/LASP)
MOPITT	Canada PI US PI	James Drummond (Dalhousie Univ.) Helen Worden (NCAR)



- ASTER
 - Hi-resolution, multi-spectral images from 15 m to 90 m resolution, plus stereo
- CERES
 - Measures Earth's shortwave, longwave, and net radiant energy budget
- MISR
 - Global multiangle images of aerosol, cloud, and surface characteristics
- MODIS
 - 1-2 day global coverage in 36 wavelengths from 250 m to 1 km resolution
- MOPITT
 - Global measures of CO

- Launch Date: December 18, 1999
- 705-km orbit
- 98.88 minute period
- 98.3 degree inclination
- 16 day repeat (233 orbits)
- 10:30 am crossing time descending orbit (originally 10:45 am)
- Design Life : 6 years
- AM constellation w/Landsat 7



The primary purpose of Terra is to enable the science community to address fundamental questions on causes and pace of global environmental change



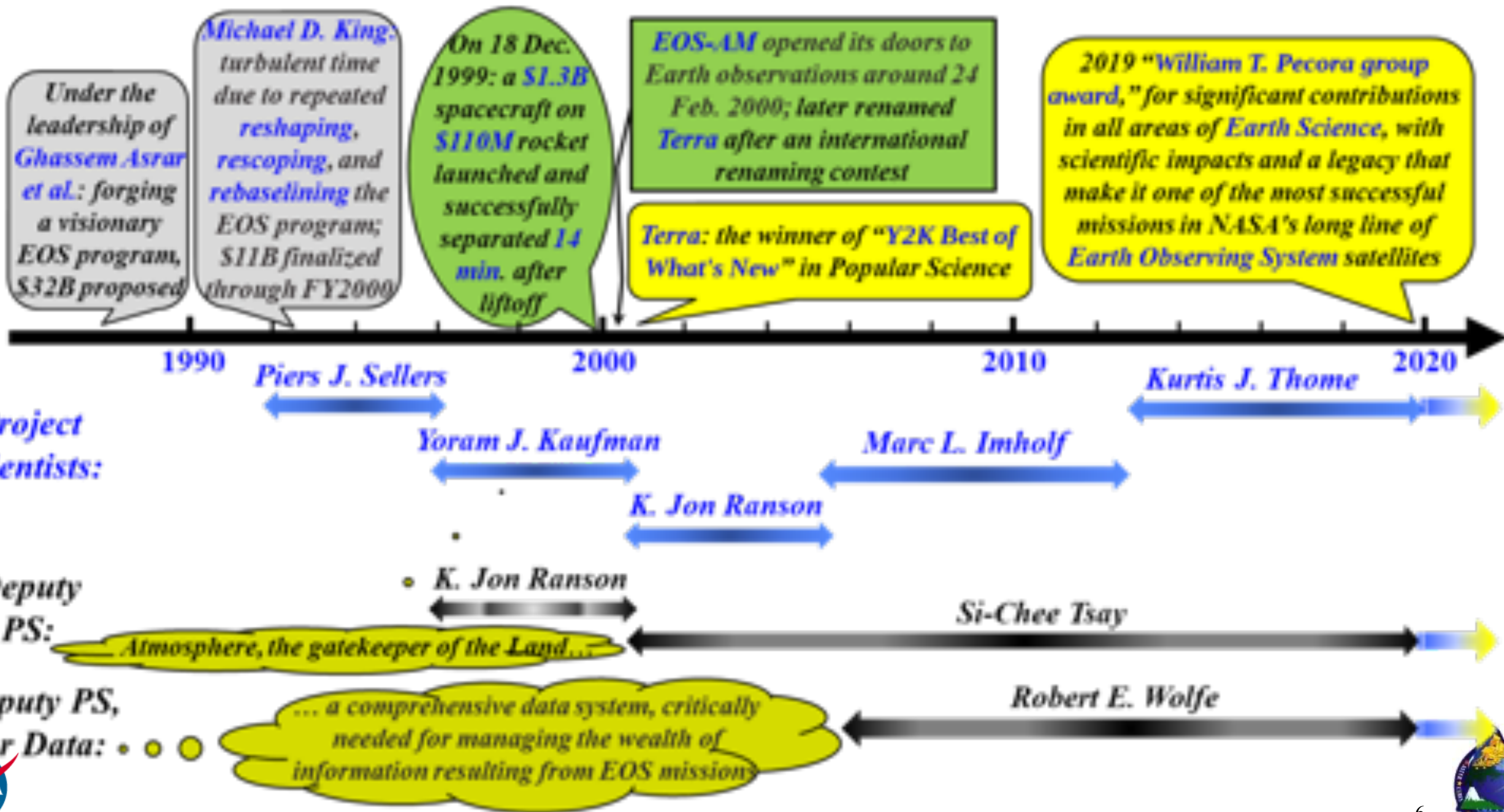
Blue Marble 2002

In 2002, NASA scientists and visualizers stitched together strips of brand new data, in natural color, collected over four months from the Moderate Resolution Imaging Spectroradiometer, or MODIS, instrument aboard Terra. This composite Blue Marble became one of the most iconic Earth images of the new century when Apple selected it as their default background for the iPhone in 2007.



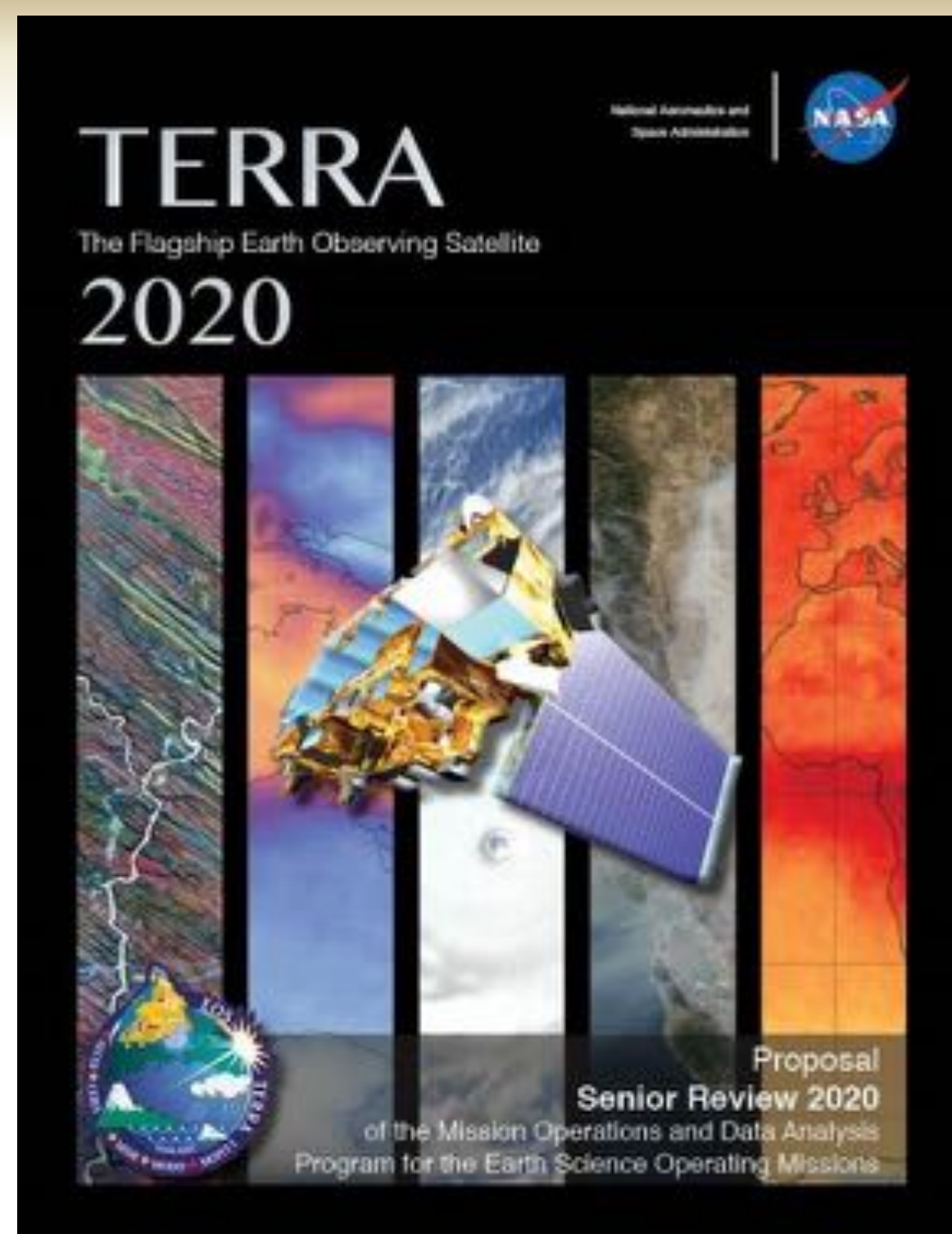
EOS/Terra: Brief History and Milestones

By Si-Chee Tsay



2020 Senior Review Proposal

- Senior Review process is now on three-year centers
 - Reduces the work load somewhat
 - Increases importance of an individual proposal
- Changes in 2020 versus 2017
 - Algorithm Maintenance support was integrated into the project proposals
 - In-guide budget assume that Terra would begin Phase F process at end of FY22 and project closeout at end of FY25



Successful Senior Review Proposal

Making a case for the importance of Terra is not a challenge
(though the Senior Review process does take some work)

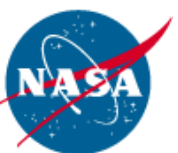
- Proposal submitted in March 2020
 - Significant work is done in preparing the proposals
 - Thanks go out to the science community for providing key data that goes into the proposals
 - Emphasized societal impacts
 - Included request for additional funding in FY23-FY25 to continue operating and not begin Phase F
- Panel Review took place in July
 - Delay from original May schedule to allow setting up the virtual aspects of the meeting
 - Pandemic complicated the review the process
- Letters were received in October giving guidance on what the Terra project is supposed to do over the next six years



Successful Senior Review Proposal

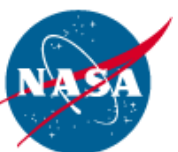
“Terra is the most important Earth Observation mission of the 21st century.”

- Panel recommended full extension and “The Senior Review Science Panel unanimously supports Terra's extension in FY 2021-2023 and FY 2024-2026 with the proposed over-guide budget.”
- Funding approved to continue mission operations through FY23
- Actions requested are
 - Need to document modifications needed to processing because of orbit changes
 - Collect new science that will result from orbit changes
 - Quantify impacts from 15 minute change in equatorial crossing time
 - Complete a review of Terra algorithms and data sets by end of 2022
 - Complete a review of the effects of MLT drift mitigation strategies by end of 2022
 - Users' Workshop to communicate orbit impacts and prepare users for mission end-of-life
 - Annual Mission Operations Review
 - *Provide a 2023 Senior Review Proposal*

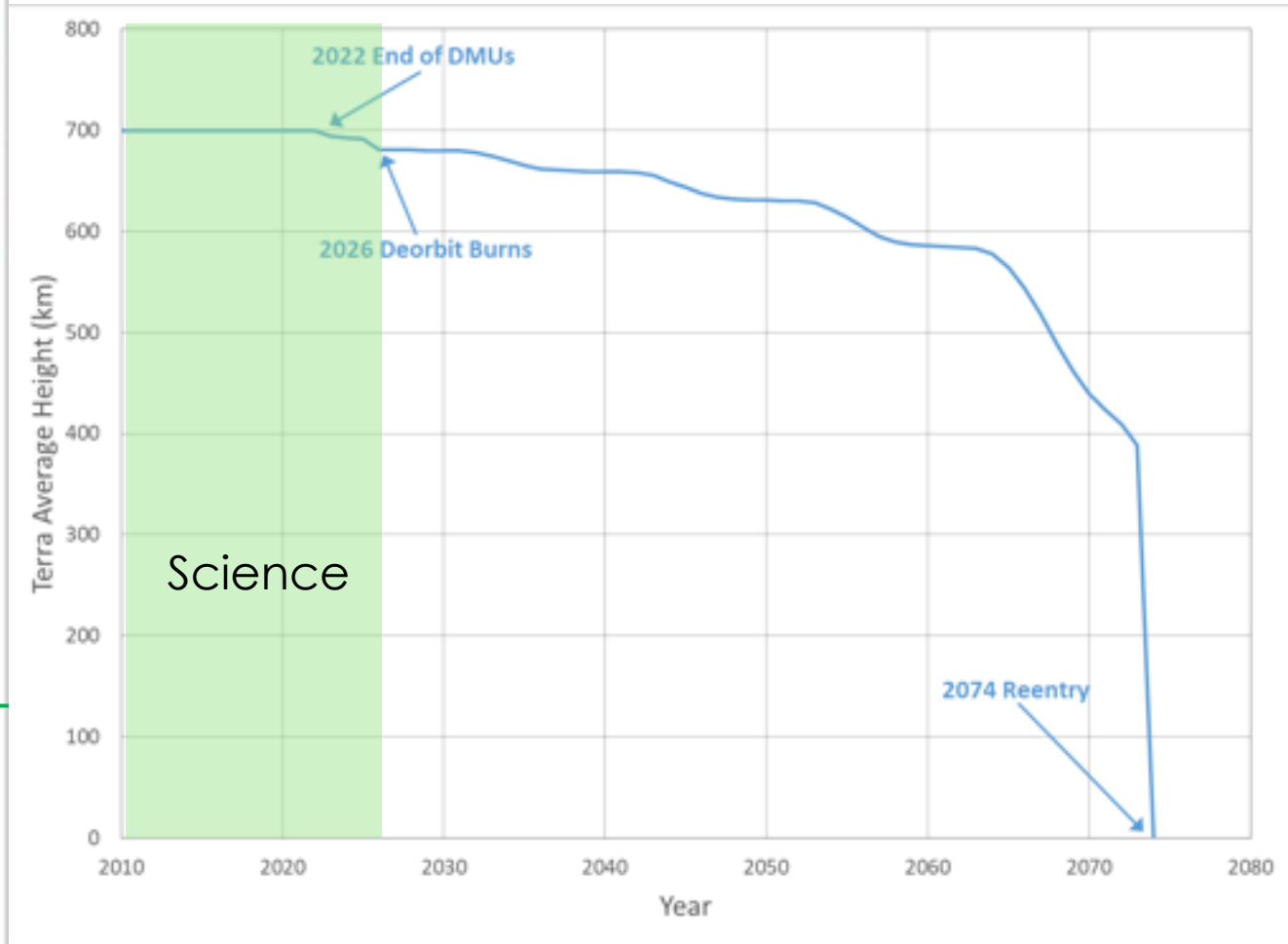
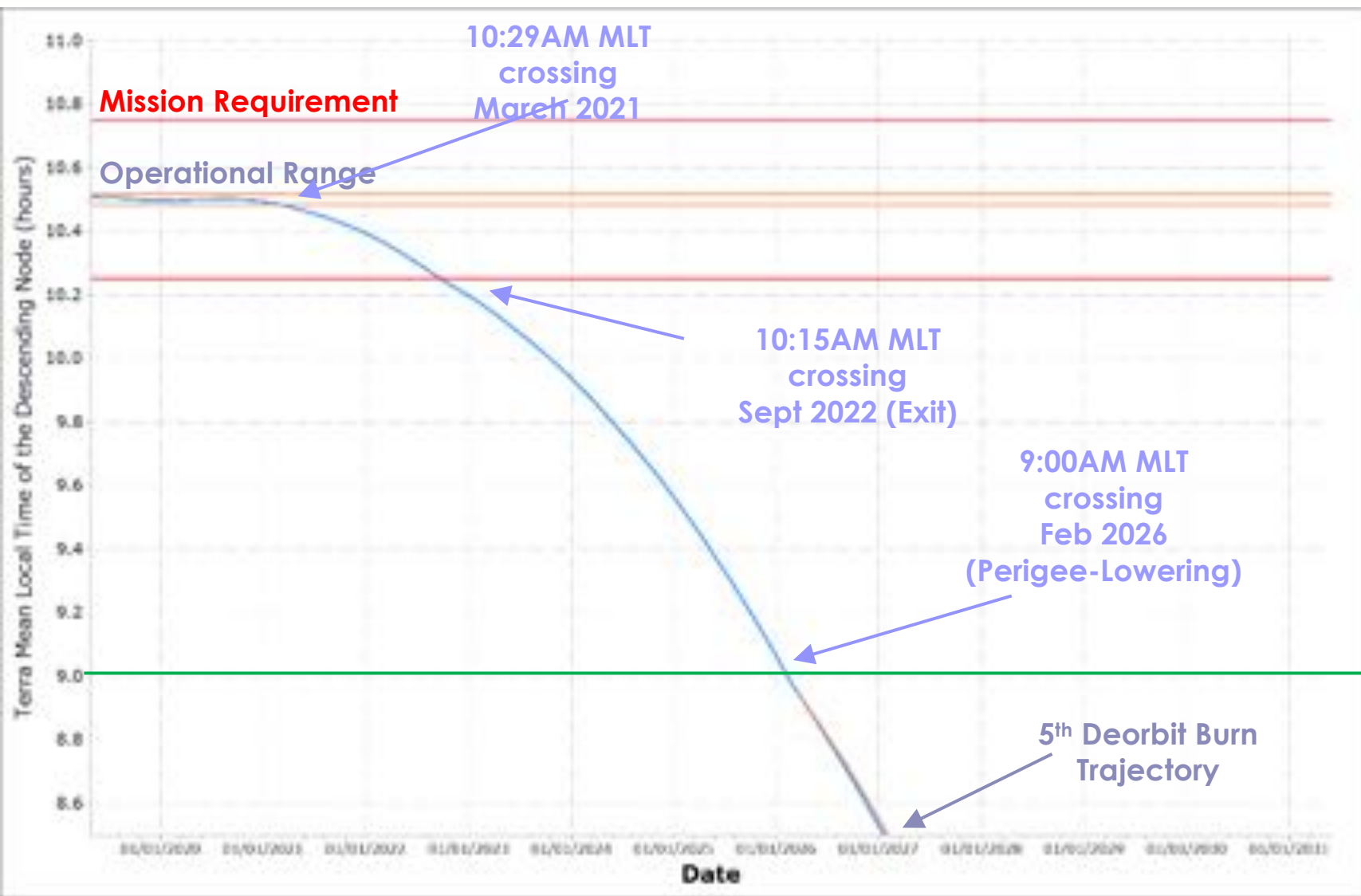


2020 Inclination Adjust Maneuvers are the last ones for Terra

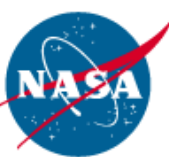
- Last inclination maneuver performed February 27, 2020
 - Crossing time has been slowly changing to an earlier crossing time
 - Still at the same altitude
 - Predict that it will exceed the two minute box sometime in Spring 2021
- Terra's original crossing time limit was set at 10:15 am
 - Current plan is to exit the 705-km constellation when Terra's crossing time reaches 10:15 am
 - Currently predicted to occur in Fall 2022
- After exit, Terra sensors will continue to collect data as the platform drifts in crossing time and altitude slowly lowers
- Data can continue to be collected during this process
- End of Mission Plan assumes a Terra passivation in in Spring 2026
 - Crossing time predicted to reach 9:00 am
 - Remaining fuel used to lower perigee prior to spacecraft passivation



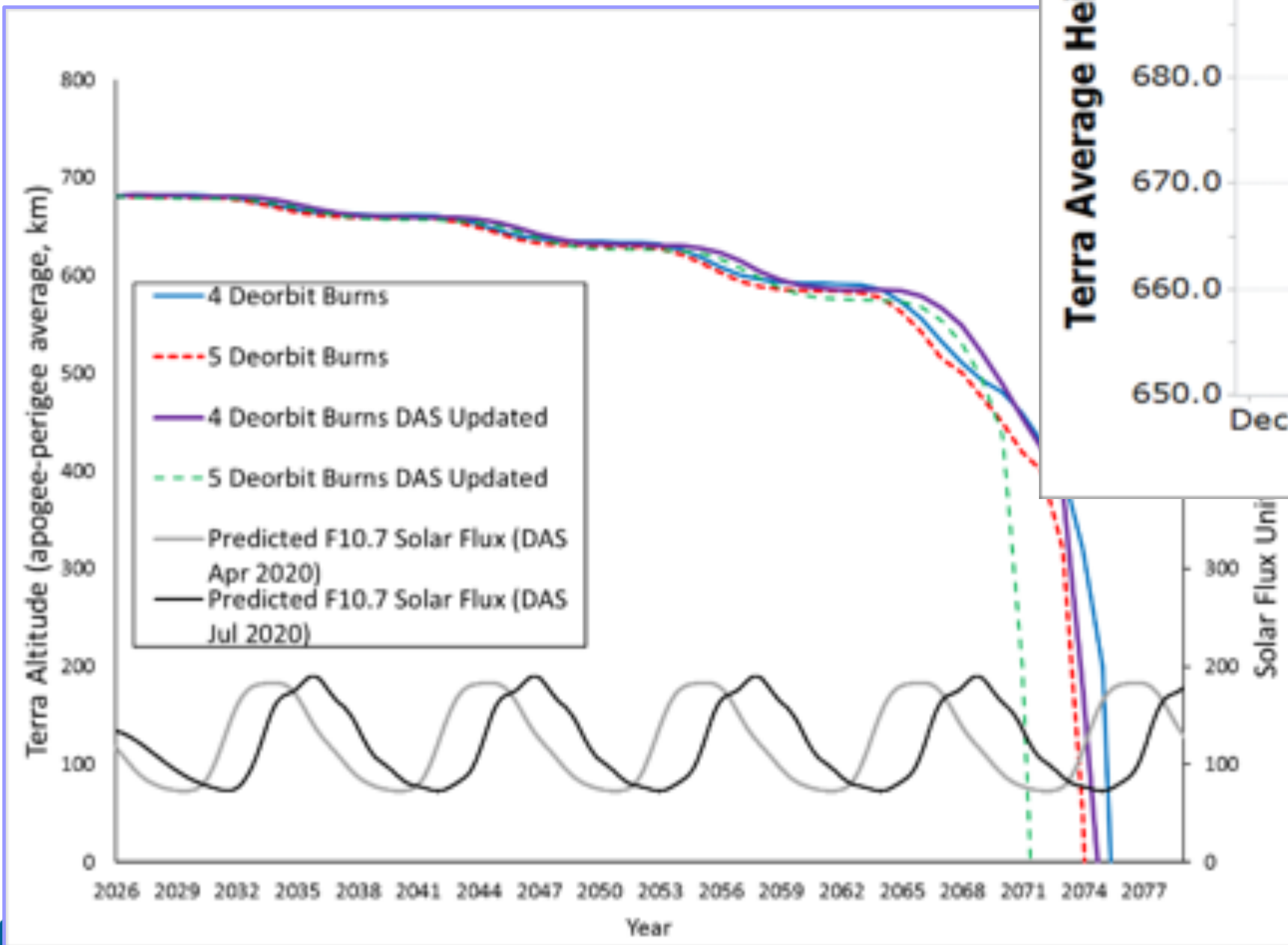
Maintain current crossing time through Spring 2020



Decommissioning Plan	MLT Violation (10:29AM)	MLT Violation (10:15AM)	Exit Year	De-orbit Burns (#)	Apogee at Depletion (km)	Perigee at Depletion (km)	Crossing time 9:00AM MLT	EOM to Reentry (years)	Reentry Date
Baseline	Mar 2021	Sept 2022	2022	5	691.1	667.0	2026	43	2069



Orbit altitude



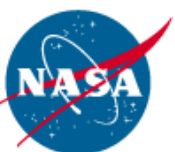
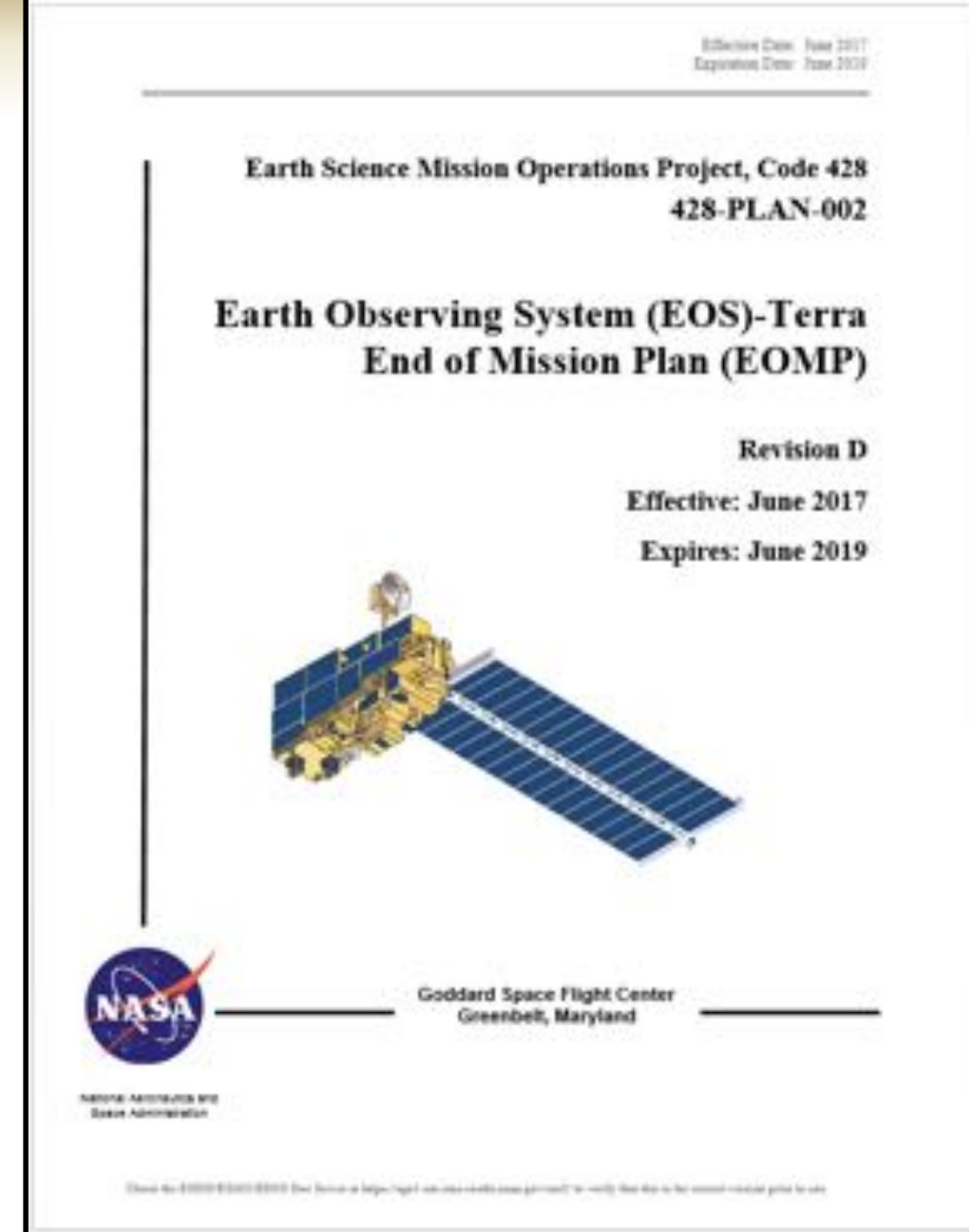
It is all described in the Terra End of Mission Plan

Document Status

- Rev D - End-of-Mission Plan Document has been revised and under review cycle
- **APPROVED - NASA HQ Signed in October 2018**

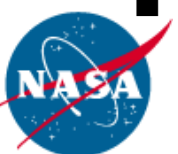
Content

- Terra will continue normal operations through **October 2020**
- Once all non-reserved fuel has been used, **MLT** will be drifted to 10:15 AM
- **September 2022**, Terra exits constellation
- Remaining fuel used to lower perigee prior to spacecraft passivation
- Exit plan is consistent with the current Constellation Operations Coordination



Terra continues to operate well

- Command & Data Handling (CDH) – **Nominal**
 - Solid State Recorder (SSR) – holds ~1 orbit of data
 - 14 of 58 SSR Printed Wire Assembly tripped off resulting in reduced recording capacity
- Communications (COMM) – **Nominal**
 - DAS Modulator Failure on 05/29/2008 (Operating on Redundant)
 - Use K-Band primarily, X-Band as needed for Science Playback
- Electrical Power System (EPS) – **Good**
 - Battery Cell and Heater Controller Anomaly (10/13/2009)
 - 1 of 24 Solar Panel Failed (9/24/2000)
- Flight Software (FSW) – Nominal
- Guidance, Navigation & Control (GN&C) – **Nominal**
 - Minor loss of sensitivity in SSSTs – updated tracker biases to compensate
- Propulsion (PROP) – **Nominal**
- Thermal Control System (TCS) – **Nominal**
- Instruments (INST) – **Nominal**
 - Only ASTER SWIR failed, all other instruments are taking science



Solid State Recorder (SSR) & Printed Wire Assembly (PWA) anomalies

- PWA failures lead to loss of data recording capabilities
- Failures have been occurring to Terra since early in the mission
- In 2019 Terra saw two PWA failures
 - 6/27/19 – MISR Buffer
 - 8/30/19 – MODIS Buffer
- At that point it was recognized that any additional PWA failures on MODIS or MISR Buffers would result in reduced science
- Instrument and operation teams met as part of Terra Working Group meeting in September 2019 to develop a strategy to address further PWA losses

PWA Failure History

	Date	Supersets	PWA	Buffer Affected	DMU
1	5/20/2001	30-31	16*	MODIS	DMU-1
2	7/30/2003	102-103	52	ASTER	DMU-2
3	9/24/2003	50-51	26	MODIS	DMU-1
4	9/25/2003	114-115	58	ASTER	DMU-2
5	10/14/2003	42 - 43	22	MODIS	DMU-1
6	7/31/2004	10 - 11	6	MISR	DMU-1
7	8/26/2005	54-55	28	MODIS	DMU-1
8	4/19/2007	58 - 59	30	MISR	DMU-1
9	1/8/2010	26- 27	14	ASTER	DMU-1
10	4/2/2012	36-37	19	ASTER	DMU-1
11	10/12/2014	112-113	57	MODIS	DMU-2
12	12/20/2017	28-29	15	ASTER	DMU-1
13	06/27/2019	74-75	38	MISR	DMU-2
14	08/30/2019	108-109	55	MODIS	DMU-2

In 2007, SS were reallocated to MODIS/MISR to DMU-2 and ASTER to DMU-1

* PWA 16 was recovered following SSR reset. Has not failed since being recovered *

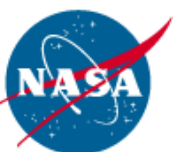


PWA strategy

	Changes considered if PWA failures occurs	Impact to Science if change	IOT Response to SSR Recycle
MODIS	<p>Current (15 PWAs) : Observations Normal 1 loss (14 PWAs) : Change to data collection ratio</p> <p>2 loss (13 PWAs) : Borrow from MISR if MISR still at 8.5 PWAs otherwise Perform SSR reset</p>	Decreased visibility of POLAR bands if data collection changes are needed	Would need approval from MODIS Science team following 2+ PWA loss for recycle
MISR	<p>Current (8.5 PWAs) : Nominal observations 1 loss (7.5 PWAs) : Reduce MISR acquisitions</p> <p>2 loss (6.5 PWAs) : Borrow from MODIS if MODIS still at 15 PWAs otherwise Perform SSR reset</p>	Trimming data at start/end of each orbit. Reduces coverage of Polar regions.	Preferred choice to recycle SSR if 1+ PWA failures occur after verifying S/C team has done its due diligence with risk assessment
ASTER	<p>Reduce number of observations for all PWA failures</p> <p>1-3 PWAs loss: Reduce low priority observations</p> <p>4 PWAs loss: Perform SSR Reset</p>	Reduced observations of lowest priority areas. Would take longer to complete "Global Map". Nighttime TIR observations would be affected.	If recycle is needed ASTER, prefers if a method that avoids recycle of DMU-1 (ASTER). (Individual PWA or DMU recycle capability is uncertain)
MOPITT	No Long Term Impact - (If PWA-31 failed LRS buffer would be moved to a Superset from another Buffer to maintain K-Band H/K)	No Impact	Defers to S/C team for risk evaluation. If low risk, okay with recycle
CERES	No Long Term Impact - (If PWA-31 failed LRS buffer would be moved to a Superset from another Buffer to maintain K-Band H/K)	No Impact	Endorses recycling "sooner rather than later" approach to recycle if low risk.

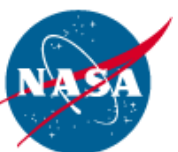
PWA anomaly occurred on Oct. 5 to MODIS storage allocation

- Terra operations team implemented the agreed upon strategy
- Reallocated MODIS collection to reduce percentage of daytime acquisitions relative to nighttime
- November 8 the allocation was set to 44% daytime and 56% nighttime
 - Buffers have not overflowed since that date
 - Leads to loss of some polar data
 - Losses are being mitigated by adjusting the start times for the daytime acquisitions



Longer-term options

- Continue as is with modest changes to percentages to minimize science impact
 - Will still lead to loss of MODIS data sets
 - Investigating possibility of direct broadcast stations but early results are not favorable
- Trade storage allocations with other sensors
 - Only option is MISR
 - Leads to loss of MISR data
- Recycle SSRs
 - Requires HQ approval
 - Should bring back the full SSR capabilities
 - Risk is that the SSR fails as a result
 - This option is what will be implemented if another PWA fails



Terra continues to add to its 20-year legacy

Has met the original 18-year, planned data record for the three EOS AM platforms

- Terra data record at its current crossing time reached 18 years in Spring 2020
- Terra data continues to play a role as the baseline data set for comparisons for recent and future missions
 - S-NPP, NOAA-20
 - New Decadal Survey recommended measurements
 - Earth Venture missions
- Two decades on orbit takes a lot of effort
 - Result of an excellent set of engineers, scientists, programmatic personnel in the 1980s and 1990s to develop Terra
 - Teamwork by these same groups and periodically adding new and younger faces ensures Terra stays healthy and relevant

