

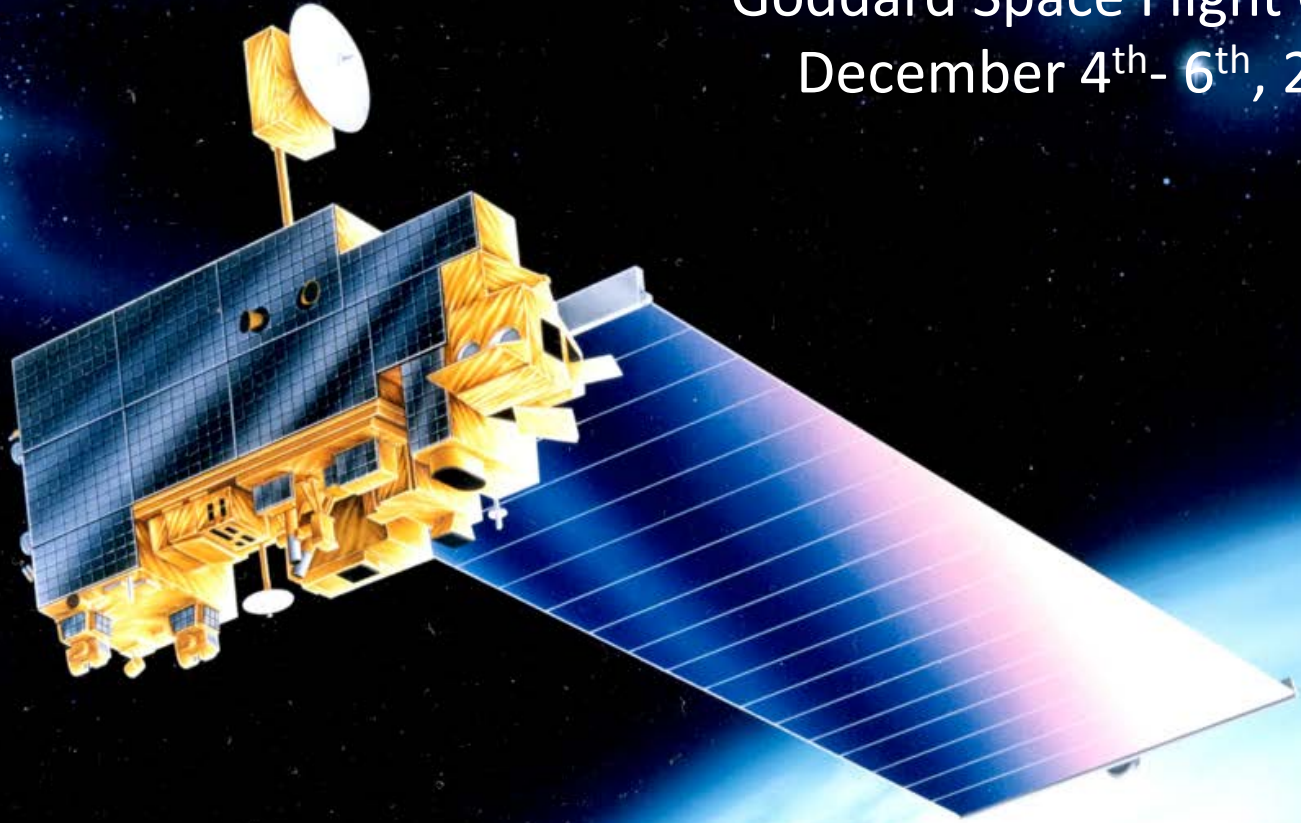
EOS Terra

Mission Status

Constellation MOWG

Goddard Space Flight Center

December 4th - 6th, 2018

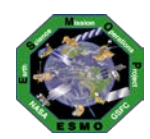


Dimitrios Mantziaras

Terra Mission Director - Code 428

phone 301-614-5234

Dimitrios.C.Mantziaras@nasa.gov



Topics



- **Mission Summary**
- **Spacecraft Subsystems Summary**
- **Recent Activities**
- **Inclination Adjust Maneuvers**
- **Conjunction History**
- **End-Of-Mission Plan**
- **Upcoming Activities**
- **Summary**
- **Backup Slides**

Terra Mission Overview

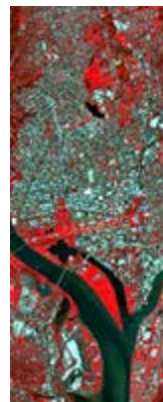


Terra Features

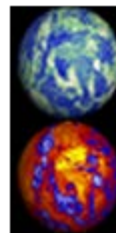
- **Launch Date:** December 18, 1999 (Atlas IIAS, VAFB)
- **Orbit:** 705 km, Sun-synchronous polar, 98.2° Inclination, 10:30 AM MLT descending node
- **Instrument Payload:**
 - **ASTER (SWIR, TIR & VNIR)** - Advanced Spaceborne Thermal Emission and Reflection Radiometer (Japan)
 - **CERES (Fore & Aft)** - Clouds and the Earth's Radiant Energy System (USA – Langley)
 - **MISR** - Multi-angle Imaging Spectro-Radiometer (USA – JPL)
 - **MODIS** - Moderate Resolution Imaging Spectro-radiometer (USA – GSFC)
 - **MOPITT** - Measurement of Pollution in the Troposphere (Canada)
- **Project Management:** Earth Science Mission Operations (ESMO)
- **Spacecraft Flight Operations:** Contracted by GSFC to KBR team and supported by NASA NENs and TDRSS
- **Instrument Operations and Science Data processing:** Performed at respective Instrument Locations where developed
- **Mission Duration:** Successfully completed Prime mission of 5 years. Currently in Extended Operations.
- **Distributed Active Archive Centers:** LP DAAC – MODIS, ASTER; Langley DAAC – CERES, MISR, MOPITT

Science

- The primary objective of the Terra Mission is to simultaneously study clouds, water vapor, aerosol, trace gases, land surface and oceanic properties, as well as the interaction between them and their effect on the Earth's energy budget and climate.



ASTER



CERES



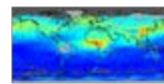
Terra (EOS AM-1)



MODIS

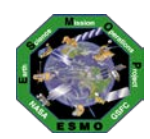


MISR



MOPITT

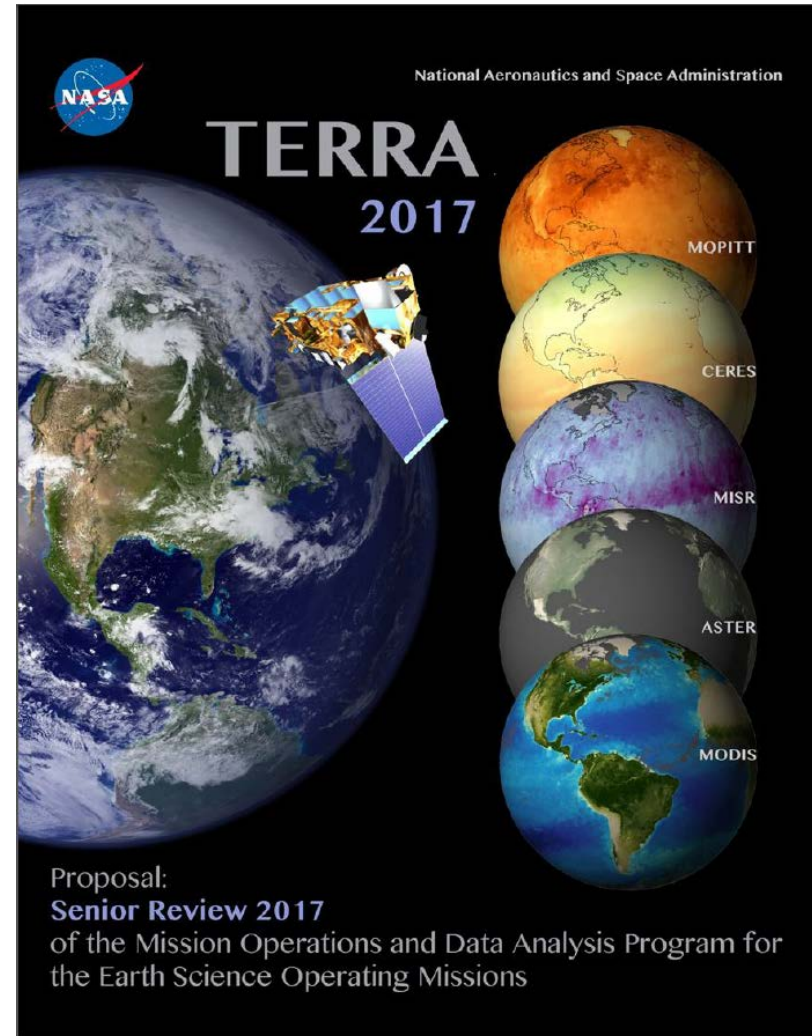


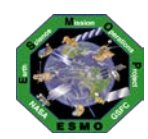


EOS Terra Mission Summary



- **May 2017:** Mission Extension Senior Review Proposal Panel Report
 - Mission extension through **FY23**
 - Senior Review submission delivered in Mar 2017
- **2018** Inclination Adjust Maneuvers
 - Spring 2018 Inclination Maneuvers
 - **IAM #51 – February 22nd**
 - Fall 2018 Inclination Maneuvers
 - **IAM #52 – October 25th**
 - **IAM #53 – November 01st**
- **10/06/18:** Terra 100,000 Orbits
- **12/18/18:** Terra **19**-Year Anniversary
 - 5-Year Design Life, 6 year goal
 - Reliability Estimates thru 2025+
 - Consumables through 2020+
- **January 2019:** EOS Flight Operations Annual Review **#13**



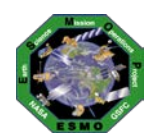


Terra Spacecraft Status



All subsystems on Primary Hardware except as noted

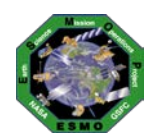
- **Command & Data Handling (CDH) – Nominal**
 - Solid State Recorder (SSR) – holds ~1 orbit of data
 - 11 of 58 SSR Printed Wire Assembly tripped off resulting in reduced recording capacity
- **Communications (COMM) – Nominal**
 - DAS Modulator Failure on 05/29/2008 (Operating on Redundant)
 - Use K-Band 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



Spacecraft Component Status



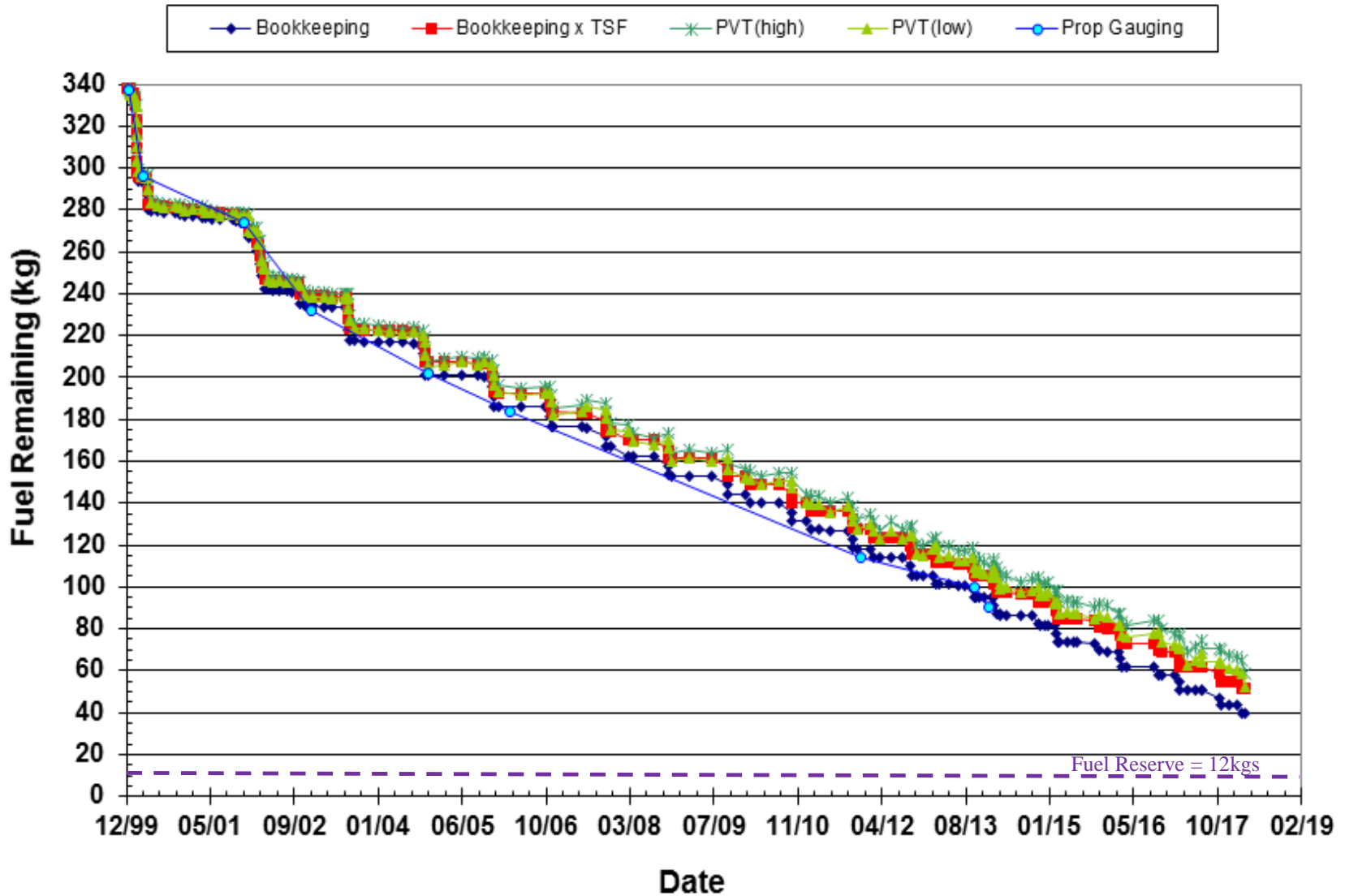
Subsystem	Component	Design	Current	Capability	Comments
EPS	Solar Array	24 Shunts	23 Shunts	96%	Degradation is minimal. Fully capable of supporting mission thru 2020 unless future failures occur
	Batteries	108 Cells	107 Cells	99%	BBAT cell #50 failed on 10/15/09.
	Batteries	36 Heater Controls	28 Heater Controls	77%	BBAT heater control failed on 4 of 9 heater groups on primary, redundant, and survival. Battery cell charging/discharging and the remaining heater groups are preventing cells from freezing. PBAT heater control performance is nominal.
TCS	MOPITTCPHTS	2	2	Full	Performance is nominal
	SWIR CPHTS	2	2	Full	Performance is nominal
	TIR CPHTS	2	2	Full	Random temperature fluctuations. Performance within requirements.
SCC	SCC	2	2	Full	Performance is nominal
COMM	HGA	2	2	Full	MDA BITE failures occur 2-3/week due to SEU. Recoverable
	X-Band	2	1	75%	DAS Modulator 1 failed (50%). Solid State Power Amplifier redundancy still available (100%).
	CTIU	2	2	Full	Performance is nominal
	OMNI	2	2	Full	Performance is nominal
CDH	MO	2	2	Full	Drift rate changes have occurred since 10/3/10. Performance is within requirements.
	SFE	2	2	Full	SFE SEU occur 1-2/year. Recoverable
	SSR	59 PWA	48 PWA	81.4%	Recycle of Data Memory Unit likely to recover all Printed Wire Assemblies
GNC	IRU	3	3	Full	Performance is nominal. 2 for 3 redundancy
	TAM	2	2	Full	Performance is nominal
	SSST	2	2	Full	Minor loss of sensitivity in SSSTs – tracker biases updated
	CSS	2	2	Full	Performance is nominal
	ESA	2	2	Full	Performance is nominal
	FSS	1	1	Full	Performance is nominal. Not currently used
	RWA	4	4	Full	Performance is nominal. 3 for 4 redundancy
	MTR	3	3	Full	Performance is nominal
Prop	REAs	16	16	Full	Performance is nominal
Instruments	ASTER - SWIR	2	2	0%	Cooler is unable to maintain detector temperature. Science Data is unusable (Fully Saturated) and is no longer being recorded. Still collecting and monitoring Engineering data.
	ASTER - TIR	2	2	Full	Performance is nominal
	ASTER - VNIR	2	2	Full	Performance is nominal
	CERES - Aft	1	1	Full	Performance is nominal
	CERES - Fore	1	1	Full	Performance is nominal
	MISR	2	2	Full	Performance is nominal
	MODIS	2	1	50%	Power Supply #2 failed, Formatter A degraded, cross-strapped. All Science is nominal.
MOPITT	2	1	50%	Displacer B and Chopper Motor failed. Loss of redundancy only. All Science is nominal.	

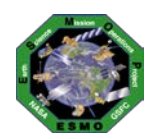


Lifetime Estimates Fuel Remaining



Terra Fuel Usage Comparison





Recent Activities



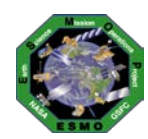
- **Propulsive Maneuvers**

- Drag Make Up Maneuver (DMU) #101 executed on 05/25/17
- Drag Make Up Maneuver (DMU) #102 executed on 06/29/17
- Risk Mitigation Maneuver (RMM) #11 (DMU #103) executed on 07/05/17
- [Inclination Adjust Maneuver \(IAM\) #49 on 10/19/17](#)
- [Inclination Adjust Maneuver \(IAM\) #50 on 10/26/17](#)
- Drag Make Up Maneuver (DMU) #104 executed on 12/14/17
- Drag Make Up Maneuver (DMU) #105 executed on 01/26/18
- [Inclination Adjust Maneuver \(IAM\) #51 on 02/22/18](#)
- Risk Mitigation Maneuver (RMM) #12 (DMU #106) executed on 03/16/18
- Risk Mitigation Maneuver (RMM) #13 (DMU #107) executed on 08/10/18
- [Inclination Adjust Maneuver \(IAM\) #52 executed on 10/25/18](#)
- [Inclination Adjust Maneuver \(IAM\) #53 executed on 11/01/18](#)

- **Calibration Maneuvers**

- MODIS Roll #179 executed on 10/09/17
- MODIS Roll #180 executed on 11/07/17
- MODIS Roll #181 executed on 12/07/17
- MODIS Roll #182 executed on 01/06/18
- MODIS Roll #183 executed on 02/04/18
- MODIS Roll #184 executed on 03/06/18
- MODIS Roll #185 waived-off on 04/04/18 due to scheduling error
- MODIS Roll #186 executed on 06/03/18
- MODIS Roll #187 executed on 07/03/18
- MODIS Roll #188 executed on 08/01/18
- MODIS Roll #189 executed on 08/30/18
- MODIS Roll #190 executed on 09/29/18
- MODIS Roll #191 executed on 10/28/18

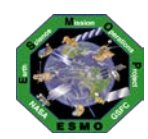
- **12/14/17: Star #493 Removal Patch Uplink**
- **12/21/17: PWA-15 Failure in ASTER Buffer**
- **01/09/18: ERPS Induced Clock Coord. Errors**
- **02/15/18: Terra Lunar Induced Solar Eclipse #41**
- **03/12/18 – 03/23/18 : MOPITT Decontamination and Hot Cal.**
- **04/19/18: CERES Safe Sequence and Calibration Load Uplink**
- **05/31/18: Auto-LUR update patch uplinked**
- **06/06/18 - 06/07/18: ASTER Science Team and Interface Meeting**
- **06/29/18: BPC Channel-A Enable TMON**
- **07/13/18: Terra Lunar Induced Solar Eclipse #42**
- **07/19/18: BBAT TMON Response Update Uplink**
- **07/26/18: CERES PROM_DUMP2 Uplink**
- **08/16/18: Safe Hold Sequence TONS update uplink**
- **09/27/18: Terra ATC Expired**
- **09/27/18 – 10/05/18: ATC Expire Instrument Recovery**
- **10/06/18: Terra Orbit #100,000**
- **10/08/18: MOPITT Decontamination Hot Cal.**
- **10/08/18: Terra HGA Power Off Anomaly**
- **10/11/18: ACE-B Rate Sensor Select Anomaly**



Inclination Adjust Maneuvers



- **Inclination Adjust Maneuvers used to maintain nominal spacecraft mean local time (descending node) of 10:30 AM**
 - **02/22/2018** **IAM #51 (320 sec burn) executed successfully**
 - **Fall 2018** **IAM #52 (320 sec burn) executed successfully**
IAM #53 (320 sec burn) executed successfully
- **Predictions indicate need to perform 3-4 maneuvers per year**
 - **2017: (2 in Spring, 2 in Fall) -- COMPLETE**
 - **2018: (1 in Spring, 2 in Fall) – COMPLETE**
 - **2019: (2 in Spring, 1 in Fall)**
 - **2020: (2 in Spring, 0 in Fall) -- last inclinations for Terra mission**



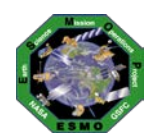
Terra High Interest Events



Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2017 (T1-T4)	0	2	0	0	1	0	2	2	0	0	0	1	8
Tier 3	0	0	0	0	0	0	1	0	0	0	0	1	2
Tier 4	0	0	0	0	0	0	1	0	0	0	0	0	1
2018 (T1-T4)	0	1	2	0	0	1	0	1	1	0			6
Tier 3	0	1	1	0	0	1	0	0	1	0			4
Tier 4	0	0	1	0	0	0	0	1	0	0			2

CARA Defines the 4 Tiers as: T1 – Notify (email/phone), T2 – Conduct Briefing, T3 – Plan Maneuver, T4 – Execute Maneuver

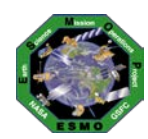
- **2005:** 4 HIEs – 1 Debris Avoidance Maneuver (DAM) performed on 10/21/2005: Terra vs. 14222 CA on 10/23
- **2006:** 1 HIE – 1 maneuver waived off due to CA. Maneuver originally planned for 01/12/2006: Terra vs. 1716 CA on 1/12 @ 17:46z
- **2007:** 4 HIEs – 1 DAM performed on 06/22/2007: Terra vs. 31410 CA on 6/23
- **2008:** 2 HIEs – 1 DAM planned and waived off: Terra vs. 82832 CA on 10/28/2008 @ 06:17z
- **2009:** 2 HIEs – No DAMs planned or performed
- **2010:** 5 HIEs – 1 DAM performed on 01/22/2010: Terra vs. 34700 CA on 1/23 @ 20:46z
- **2011:** 20 HIEs – 2 DAM planned and waived off: (1) Terra vs. 26181 CA on 3/28/2011 @ 12:14z (2) Terra vs. 30440 Repeating CA 05/07-09/2011
- **2012:** 19 HIEs – 1 maneuver waived off due to CA. Maneuver originally planned for 05/31/2012: Terra vs. 37789 CA on 6/1 @ 22:49z
- **2013:** 17 HIEs – 7 that required significant action
- **2014:** 24 HIEs – 6 that required DAM execution or nominal maneuver waive-off and replanning
- **2015:** 33 HIEs – 8 that required DAM execution or nominal maneuver waive-off and replanning
- **2016:** 11 HIEs – 0 that required DAM execution or nominal maneuver waive-off and replanning
- **2017:** 8 HIEs – 1 that required DAM execution or nominal maneuver waive-off and replanning
- **2018 thru present: 6 High Interest Events (HIEs)** – 1 that required DAM execution or nominal maneuver waive-off and replanning
 - RMM #12 executed on 3/16/18 -- Terra vs. 33666 with TCA of 03/16/18 @ 17:35z
 - RMM #13 executed on 8/10/18 -- Terra vs. 81010 with TCA of 08/11/18 @ 19:50z



ESMO RMM Planning Automation



- **ESMO has updated its Close Approach (CA) Process Flow to move towards a more Automated approach**
 - Prepares for future increased object catalog w/ Space Fence
 - Reduces workload for each event
 - Keeps solution “at the ready” for short notice events
- **ESMO Flight Dynamics team has developed an autonomous ephemeris generation tool**
- **Ephemeris built off optimal and constrained cases solved for by the Collision Risk Management System (CRMS)**
- **CARA accepts delivery of these ephemeris and ships them to JSpOC for screening**
 - Delivery to CARA is now automatic based on logic built into the FDS ephemeris tool to whittle ephemeris down from maximum of eight generated to a maximum of five delivered
 - Any other options needed can be sent manually
- **Screening results automatically compiled and outputted via an email report from CRMS**
- **Auto Ephemeris Generation implemented in February 2017**
- **Auto Ephemeris Delivery implemented in February 2018**
- **ESMO now exercising the CARA Devolution Pilot Program (other presentation)**



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

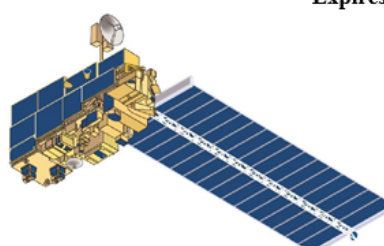
- Terra will continue normal operations through **October 2020**
- Once all non-reserved fuel has been used, MLT will be drifted to 10:15 AM
- **August 2022**, Terra exits constellation
- Remaining fuel used to lower perigee prior to spacecraft passivation
- Exit plan is consistent with the current Constellation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


Effective Date: June 2017
Expiration Date: June 2019

Earth Science Mission Operations Project, Code 428
428-PLAN-002

**Earth Observing System (EOS)-Terra
End of Mission Plan (EOMP)**

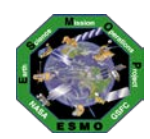
Revision D
Effective: June 2017
Expires: June 2019



 National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

Check the ESDIS/ESMO/EDOS Doc Server at <https://eps1-cm.csa.nasa.gov/cm3/> to verify that this is the correct version prior to use.



Upcoming Activities



Upcoming Activities

IAM #53 **11/01/18**

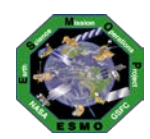
Terra FSSE CCB **11/08/18**

Devolution Parallel Ops Start **11/25/18**

Aqua and Terra ESMO Decommission Peer Review **11/29/18**

Terra 19th Anniversary Launch **12/18/18**

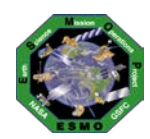
IAM #54 **February 2019**



Summary

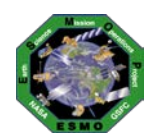


- **Terra remains very healthy 18+ years into the mission**
 - Electrical Power Subsystem performance has been stabilized following 2009 anomaly
 - Fuel Remaining to continue operations to 2020 and beyond
- **Data Capture percentages continue at ~100%**
- **Collision Avoidance events continue to be part of routine ops**
 - Low atmospheric drag is providing additional challenges
- **End of Mission Plan (Rev D) **officially approved/signed****
 - Goddard signed/approved version made it to NASA HQ on 05/11/18
 - **All signatures received in October 2018**



FUTURE PLAN*

*Will be updated if a Summer IAM is executed



Terra Lifetime Maneuvers

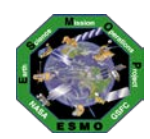


- **Remaining Orbit Maintenance Maneuvers**

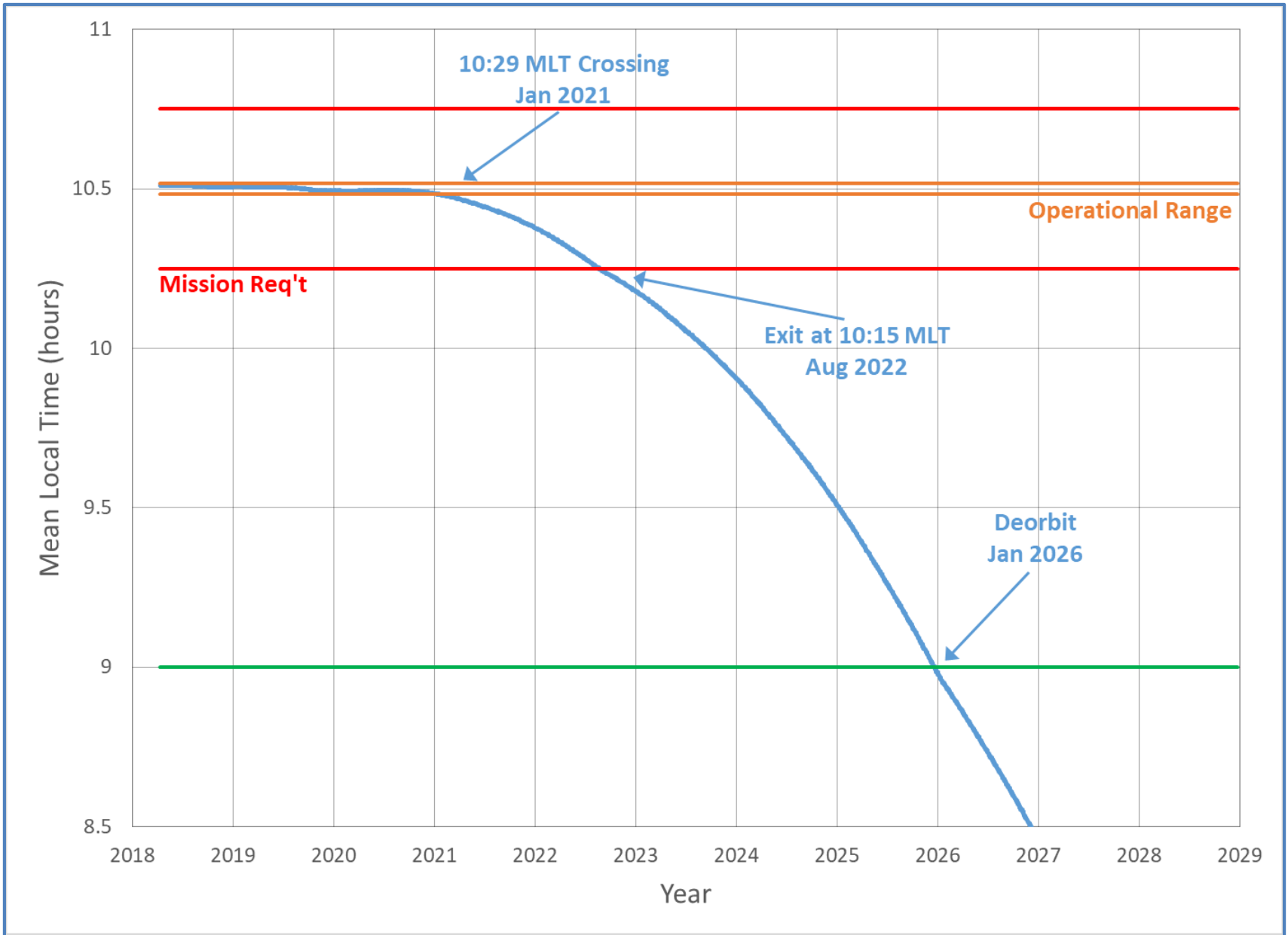
Mission Year	Inclination Maneuvers	DMU Maneuvers	Fuel Used (kg)	Fuel Remaining (kg)
2018	1 Spring, 2 Fall	2	10.60	45.83
2019	1 Spring, 2 Fall	2	10.51	35.31
2020	2 Spring, 0 Fall	1	6.89	28.42
2021	0 Spring, 0 Fall	3	0.30	28.12
2022	0 Spring, 0 Fall	3	0.38	27.74

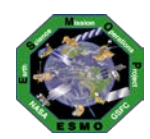
- **Constellation Exit and Deorbit Maneuvers**

Mission Date	Maneuver Type	Fuel Used (kg)	Fuel Remaining (kg)
08/31/2022	Envelope Exit #1	3.39	24.35
08/31/2022	Envelope Exit #2	3.37	20.97
1/08/2026	Deorbit #1	3.36	17.62
1/13/2026	Deorbit #2	3.34	14.28
1/15/2026	Deorbit #3	3.32	10.96
1/20/2026	Deorbit #4	3.30	7.66
1/22/2026	Deorbit #5	3.28	4.38

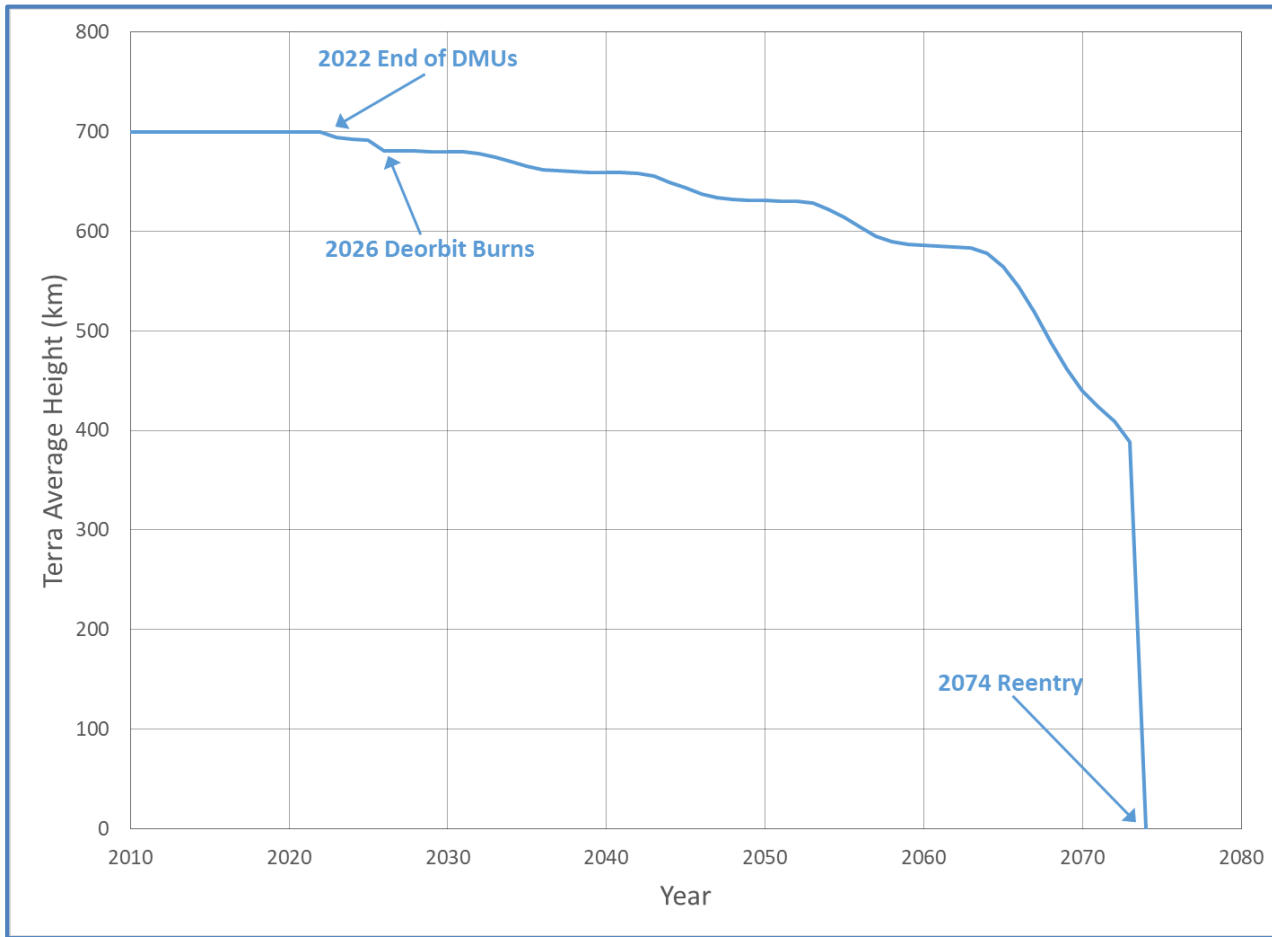


Mean Local Time

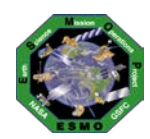




Lifetime Average Height (from DAS)



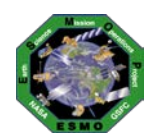
Decommissioning Plan	MLT Violation (10:29AM)	MLT Violation (10:15AM)	Exit Year	De-orbit Burns (#)	Apogee at Depletion (km)	Perigee at Depletion (km)	End of Mission - EOM (9:00AM MLT)	EOM to Reentry (years)	Reentry Date
Baseline	Jan 2021	Aug 2022	2022	5	692.3	669.7	2026	48	2074



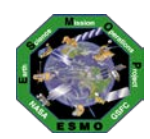
Conclusion/Summary



- It was determined officially that Terra does not require waivers
- Based on that fact, the decision for Terra's future was in the hands of the Earth Science Division @ NASA HQ
- We received written approval in February 2018 to proceed ahead with our proposed maneuver plan and EOMP signed in October 2018
- Plan is for Terra to Exit Constellation in August 2022 and end mission in early 2026

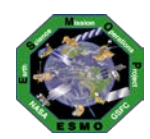


Questions



Additional Slides

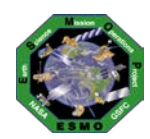
- **Orbit / Inclination / MLT Maintenance**
- **WRS Ground Track Error**
- **EPS Performance**
- **Drag Model Info**
- **OSMA Waiver Email**
- **NASA HQ Email**



Orbit/Inclination/MLT Maintenance



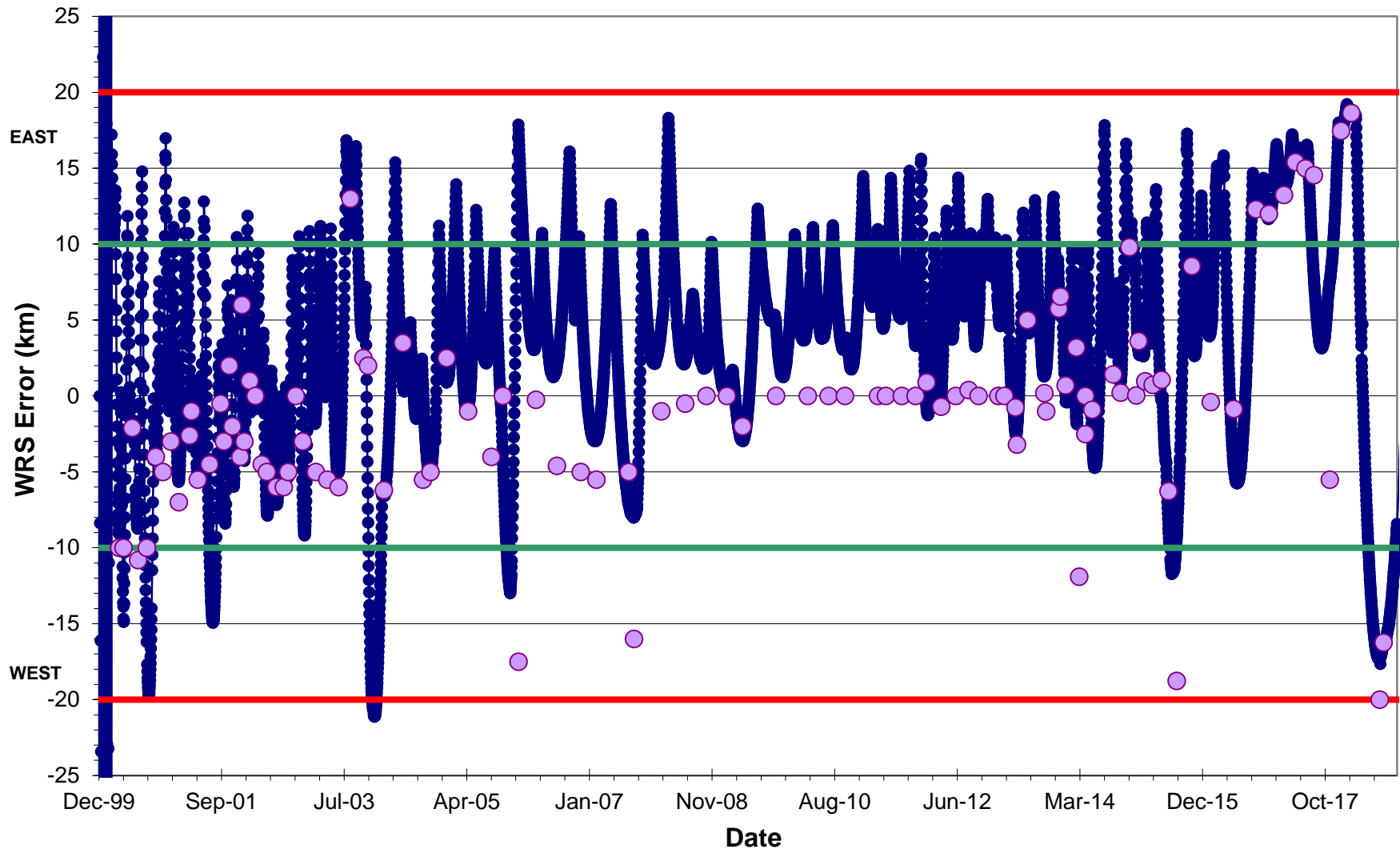
- **Requirement:** Mean Local Time (MLT) maintained between 10:15 and 10:45 measured at the Descending Node.
- **Goal:** Maintain Terra mean local time of the descending node (MLTDN) below 10:31.
- **Constraint:** OCO-2 has requested Terra maintain a MLT less than 10:31 for the duration of its lifetime to maintain a safe separation at the poles.
- **Requirement:** Maintain WRS-2 ground track error, 0 +/-20 km.
- **Requirement:** Maintain Frozen orbit with Argument of Perigee at 90 degrees +/-20 and Eccentricity of 0.0012 +/- 0.0004.
- **Constraint:** Maximum burn duration limited to 320 seconds by spacecraft manufacturer. Complete yaw slews and inclination maneuvers during spacecraft orbital night. Maneuver close to spring and fall equinox to maximize efficiency.

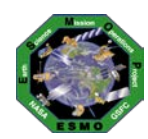


WRS Ground Track Error (GTE)



TERRA WRS Groundtrack Error at the Descending Node
(Maneuver planning targets included)

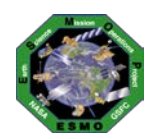




EPS Subsystem Performance



- **Bus Load: Nominal**
 - Average bus load: [2298.133 Watts](#)
 - Average housekeeping current: [11.886 A](#)
 - Total instrument current: [7.064 A](#)
- **Battery Performance: Nominal with exception of anomalous BBAT condition**
 - BBAT cell # 50 failed following IAM #24 on October 13 (DOY 286) 2009
 - BBAT Voltage Temperature curve changed to better reflect a failed cell
 - BBAT heater control electronics (HCE) anomaly occurred following IAM #24 on October 13 (DOY 286) 2009
 - Performed soft reset, power cycle, switching to redundant side and re-enabling one of the nonfunctioning heater groups to recover HCE functionality without success
 - At least 4 of 9 BBAT heater groups are no longer being controlled
 - Heater control setpoints changed for controllable heater groups to reduce the thermal gradient
 - PBAT Charge/Discharge Ratio was reduced from 105% to 104% on April 25, 2013 in an effort to extend PBAT life
 - PBAT BPC Channel A Disabled January 14, 2014; increases BBAT cold temperatures due to increased discharge
 - PBAT Charge/Discharge Ratio was reduced from 104% to 103% on August 20, 2015 in an effort to extend PBAT life
- **Battery Temperatures: Nominal with exception of anomalous BBAT data**
 - PBAT and half of BBAT Battery temperatures are regulated by flight software to $\approx -1^{\circ}\text{C}$ to -5°C
 - Almost half of BBAT cell temperatures are below normal (but stable) in the -5°C to -13°C range
- **Battery Voltages (BBAT)**
 - Minimum battery voltages at [66.148 Volts](#)
- **Solar Array**
 - Last offset adjustment performed on [October 12, 2018](#)
 - Average drift rate for the month, [0.631 deg/day](#)
 - Present offset drift rate is [increasing](#)
- **BBAT Cell with Lowest Temperature (excluding Cell #50)**
 - Cell # 21 : [-11.05°C](#)
 - Thermal Gradient(avg): [7.29°C](#)



OSMA Official Direction



From: Aleman, Suzanne M. (HQ-GD000)
Sent: Wednesday, November 02, 2016 11:37 AM
To: Yuhas, Cheryl L. (HQ-DK000) <cheryl.l.yuhas@nasa.gov>
Cc: Liou, Jer-chyi (JSC-XI411) <jer-chyi.liou-1@nasa.gov>; Hull, Scott M. (GSFC-5920) <scott.m.hull@nasa.gov>
Subject: FW: Terra need for Orbital Debris waivers

Hi Cheryl,

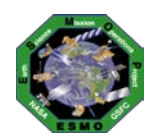
I received your voice mail regarding the question on whether a waiver is needed for the 25 year rule for TERRA.

I consulted with J. C Liou on this question we have concluded that a waiver is not needed. Please see the e-mails below.

Please let me know if you have any questions.

Best regards,

Sue Aleman
NASA HQ OSMA
MMOD Program Executive



NASA HQ Official Direction



From: Webb, Charles E. (HQ-DK000)

Sent: Friday, February 02, 2018 3:45 PM

To: Mantziaras, Dimitrios C. (GSFC-4280) <dimitrios.c.mantziaras@nasa.gov>

Cc: Watson, Wynn J. (GSFC-4280) <wynn.j.watson@nasa.gov>; Moyer, Eric M. (GSFC-4280) <eric.m.moyer@nasa.gov>; Dell, Gregory T. (GSFC-4280) <gregory.t.dell@nasa.gov>; Thome, Kurtis J. (GSFC-6180) <kurtis.thome@nasa.gov>; Wilson, Jamie Leigh (HQ-DK000)[SCIENCE SYSTEMS AND APPLICATIONS INC] <jamie.l.wilson@nasa.gov>; Cauffman, Sandra A. (HQ-DK000) <sandra.a.cauffman@nasa.gov>; Ianson, Eric (HQ-DK000) <eianson@nasa.gov>; Neeck, Steven (HQ-DK000) <steven.neeck@nasa.gov>

Subject: Re: Terra Future Maneuver Plans Slides

Dimitrios,

Sandra Cauffman has given HQ/ESD concurrence on the IAM plans for Terra through 2020. You're all set for the February maneuvers and beyond.

Have a good weekend,

Charles