Terra: Aging Spacecraft and Considerations of Maintaining Mean Local Time vs. Maintaining Altitude and Allowing MLT to Drift

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Terra status

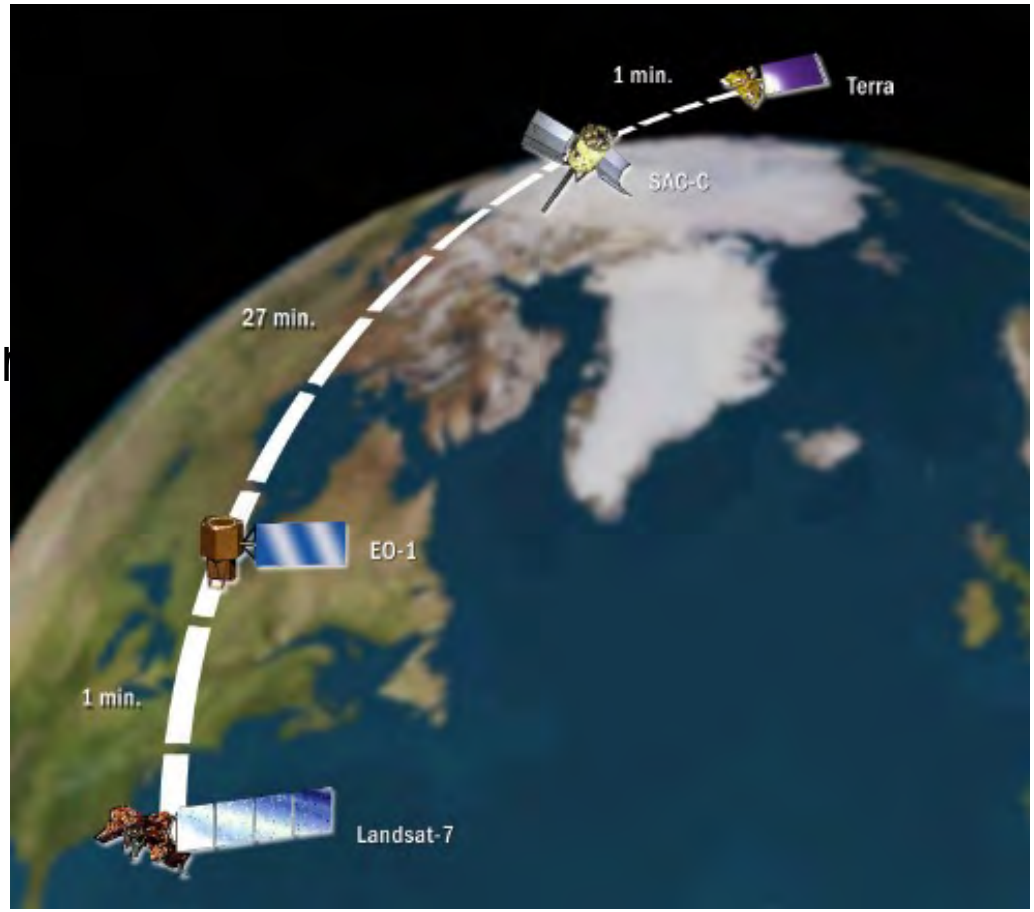
Terra and its five sensors remain very healthy 14+ years into its mission

- Terra spacecraft can support full science operation
- All instruments, except ASTER's SWIR bands, being fully operational
- Terra is expected to be functional through 2020 based on predicted battery performance and available fuel
  - No other life-limiting subsystem-specific issues
  - Result of well-built and engineered system
- Success of Terra also due to a collaborative effort between
  - Science teams
  - Algorithm developers
  - Instrument teams
  - Flight Operations Team

AM Constellation Overview

Terra is part of the AM (or Morning) Constellation consisting of 4 satellites

- Landsat-7, launched in April 1999
- Terra launched in December 1999
- EO-1 and SAC-C added i November 2000
- SAC-C no longer in constellation and EO-1 drifting



AM Constellation

16-day, 705 km orbit with descending morning crossing time

- Morning constellation not as populated or in close formation as the A-Train
  - For instance, Landsat 5 and Landsat-8) considered to be in morning constellation due to the orbit similarities
  - Landsat 5 is no longer operational
  - Landsat 8 is eight days out of phase with M-train
  - Landsat 7 will likely start orbit lowering prior to Terra
- All factors may give Terra more flexibility for end-of-life options

Orbit maintenance tutorial

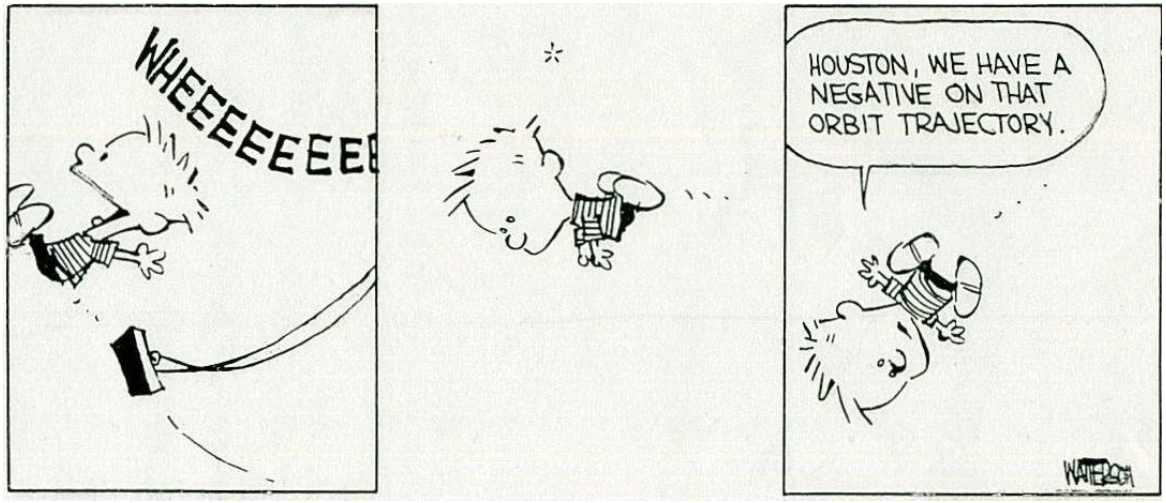
Participating in a constellation requires periodic orbital maneuvers to maintain Terra's orbit

- Science requirements for Terra also define orbital parameters
- Key orbital parameters from a constellation and science standpoint are
  - Orbital altitude (apogee and perigee)
  - Mean local time (MLT) of crossing
- Orbital maneuvers used to maintain a safe orbit are
  - Drag makeup maneuver (DMU)
  - Inclination adjust maneuver (IAM)
  - Risk mitigation maneuver (RMM) or debris avoidance maneuver (DAM)

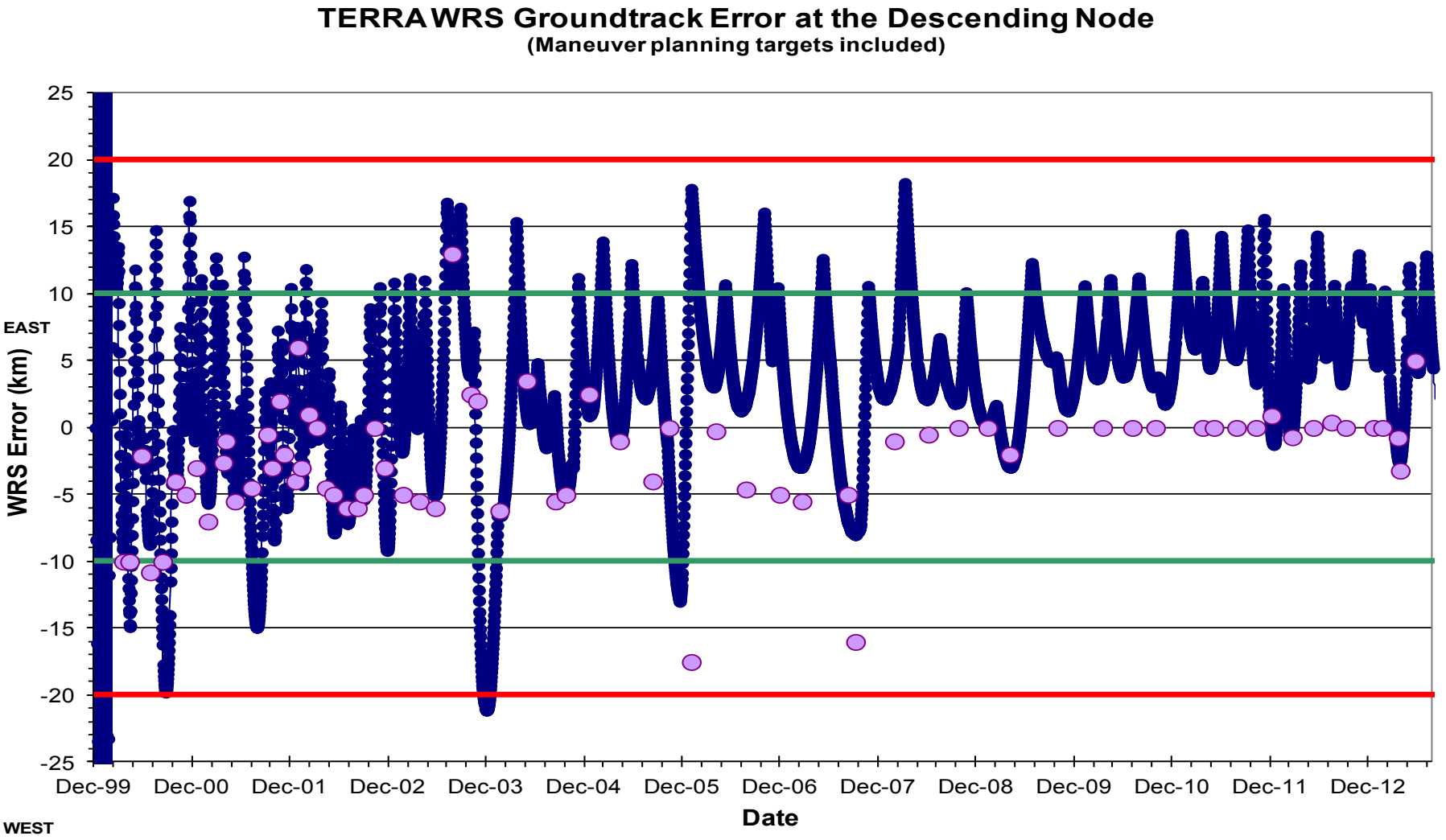
Orbit maintenance tutorial

Fuel is often a life-limiting factor for long-life platforms

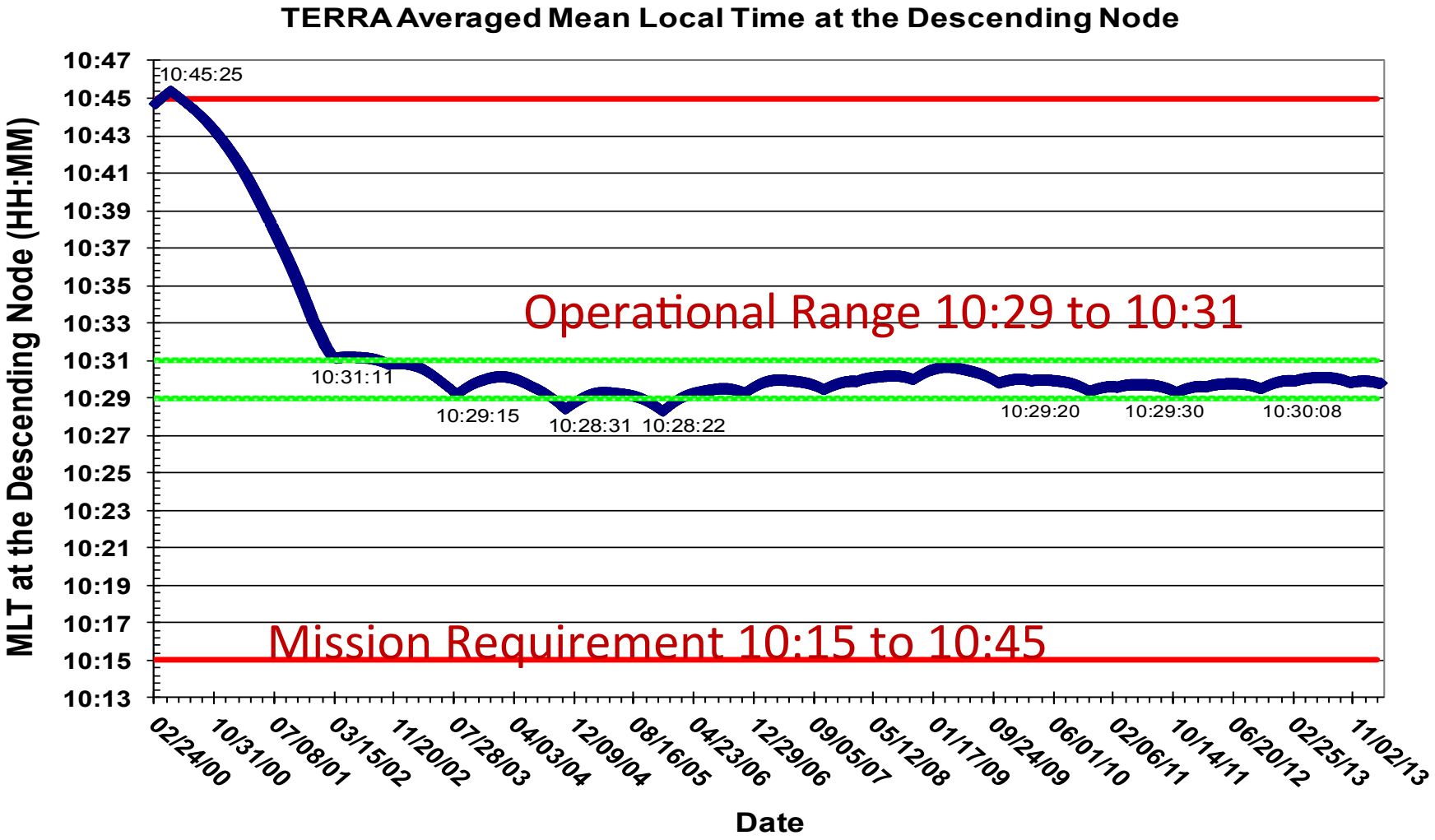
- Amount of maneuvering fuel is a trade between platform weight at launch and expected platform life
- Accurate orbit insertion by launch vehicle increases fuel on platform for maneuvering
- One can view fuel limitations as a good thing since it indicates platform is performing beyond its design life



Maneuvers maintain ground track



Maneuvers maintain crossing time (MLT)



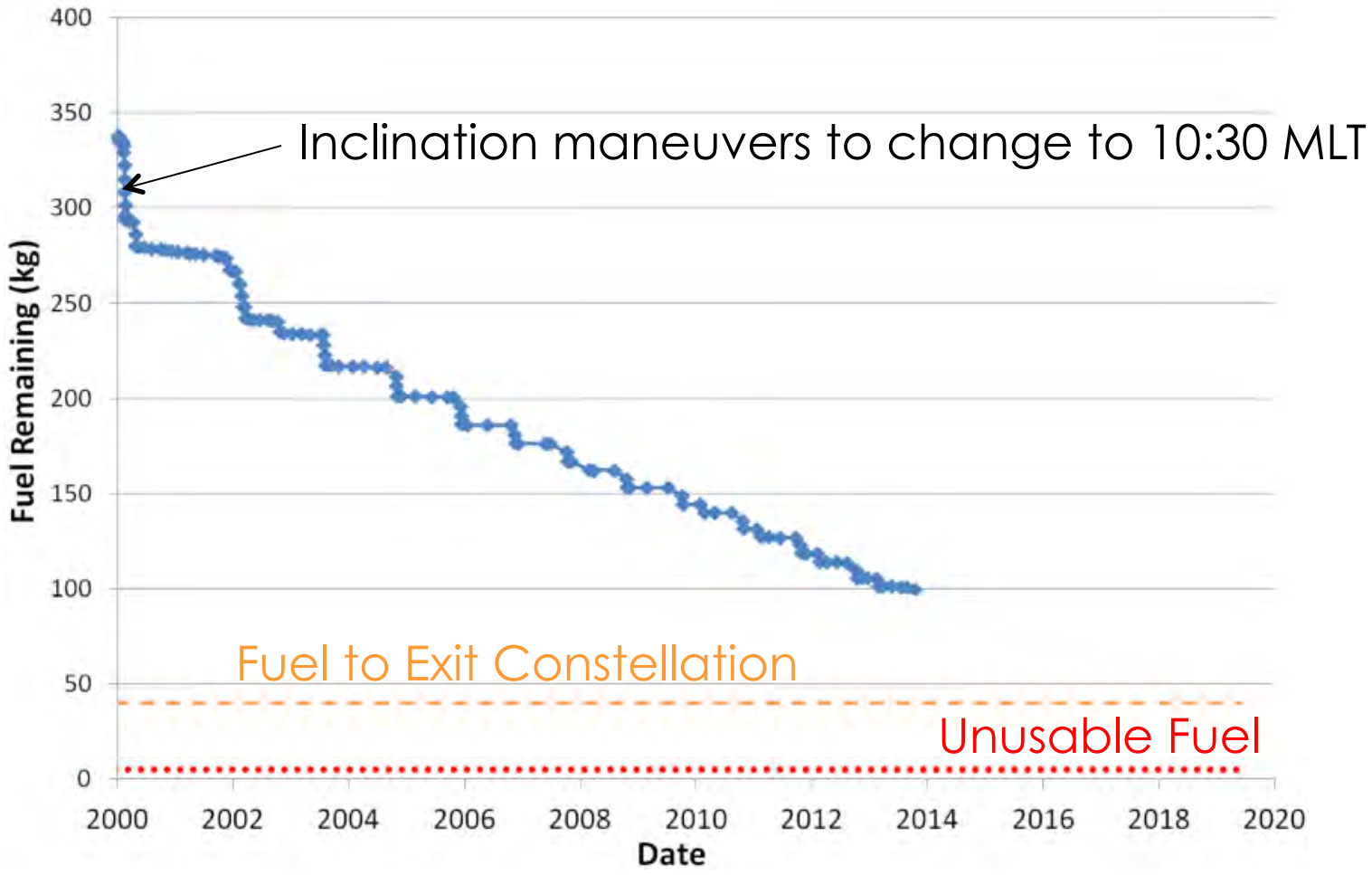
Terra fuel usage

Terra's fuel is used for orbit maintenance, debris avoidance, and constellation exit

- Current estimates show ~100 kg remaining
  - Approx. 40 kg is needed for constellation exit (given current constraints)
  - Leaves 60 kg of usable fuel for maneuvers
- Each inclination adjust maneuver (IAM) burns ~4 kg
- Each drag makeup maneuver (DMU) ~0.4 kg
- Need to determine how to use the remaining fuel to maximize benefits for the science community

Terra fuel usage

Fuel usage by Terra as a function of time since launch



Terra is using its fuel

Flight Operations Team needs inputs from Terra scientists as to how to use remaining fuel

- Goal is to optimize length of mission while keeping the risk to morning and afternoon constellations low
- Science trades are effectively related to
  - Maintain crossing time (MLT) – implies changes in orbit altitude
  - Maintain orbital altitude – implies changes in MLT
- More complicated and detailed than this but this is the basic concept
- Terra project science office is seeking input to help guide the Flight Operations Team's recommendation to the Mission Operations Working Group
- Final recommendation goes to NASA HQ for approval

Example impact to Terra data from changing MLT

Some impacts from changing MLT affects all Terra instruments equally

- Long-term data records are impacted by changes in MLT
- Earlier crossing time means larger solar zenith angle (sun closer to the horizon) and less solar heating
  - Lower signal levels in reflective bands
  - Lower temperatures
  - Leads to lower signal to noise ratio
- Cloud probabilities decrease
  - Clear-sky science energy studies easier
  - Lower impact of clouds on surface products

Impact to Terra data from changing orbit

Changing orbital altitude also has platform-wide science impacts

- Long-term data records will include changes in spatial coverage
- New geometric processing algorithms may need to be developed
  - Effects from scan rates and integration times
  - Parallax corrections
- Lowering altitude to move out of constellation will
  - Decrease spatial coverage (swath width)
  - Improve spatial resolution
  - May cause gaps in spatial sampling

Terra Project plans for evaluating MLT question

Terra Project Science Office is working closely with Instrument and Flight Operations Teams

- Poll the Instrument teams as to preferred approaches
  - FOT will provide a list of possible scenarios (large number)
  - Instrument teams will help reduce the number of possible scenarios to evaluate
  - Detailed analysis of this smaller number of scenarios by FOT
  - Instrument teams will help select preferred methods
  - FOT presents these preferred methods to MOWG
- Go through a few examples to illustrate

Fuel usage scenarios – starting assumptions

Predictions of fuel usage depends on the goals of the science community

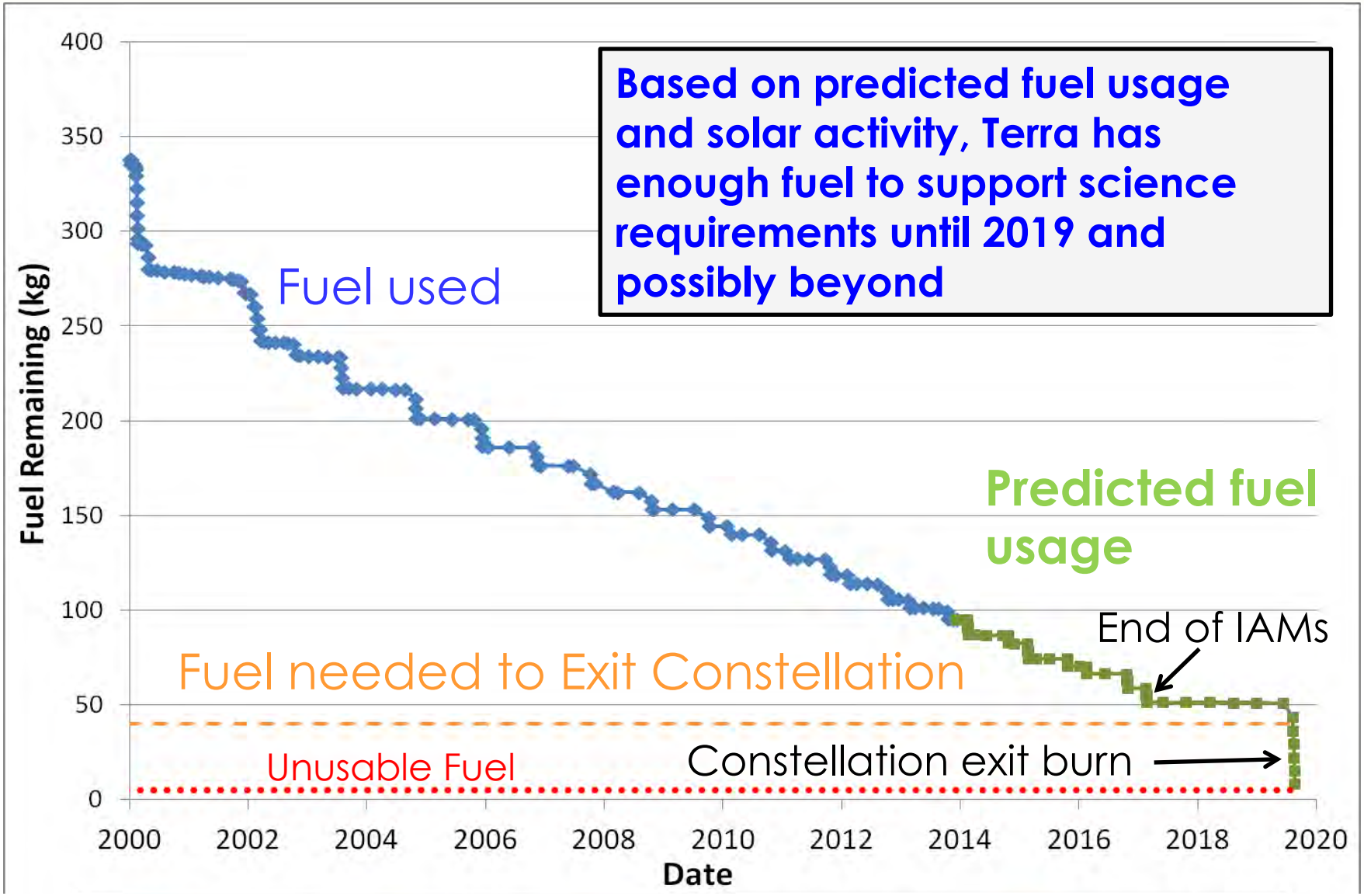
- 5 kg of propellant will remain in the propulsion lines as unusable
- Maneuver lengths and timing limitations to ensure platform health force use of less efficient apogee burns
- Terra's exit constraints follow the Afternoon Constellation Operations Coordination Plan
  - Apogee of exiting spacecraft must be at least 2 km below minimum perigee of current constellation members
  - Terra's apogee must be below 692 km

Baseline option

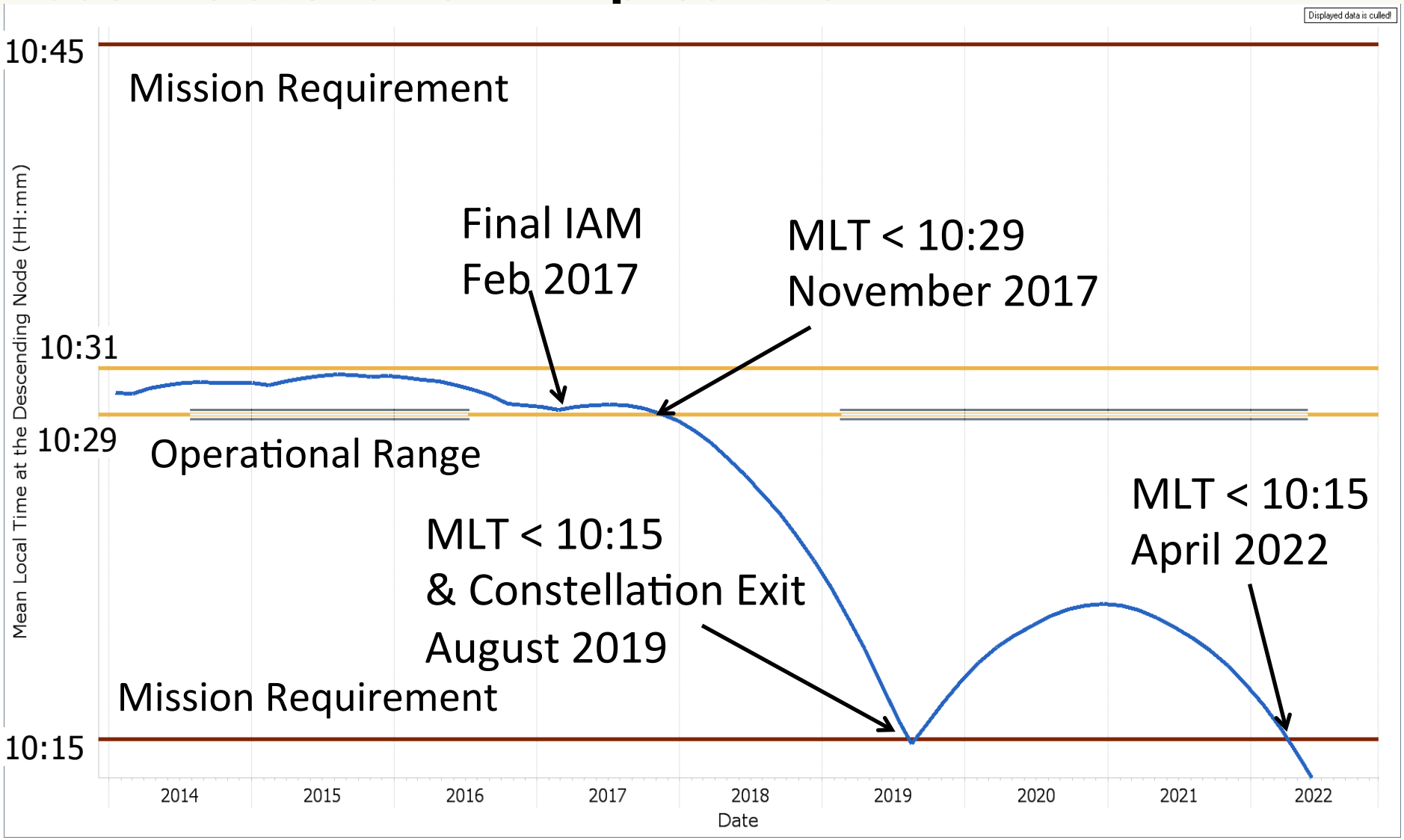
Continue current operations until constellation exit fuel reserve is reached

- Estimated to be early 2017 when we would stop performing inclination maneuvers
- MLT drifts outside of 10:29 operational range in late 2017 and continues drifting until 10:15 Mission Requirement
- Maneuvers to exit the constellation to lower Terra's altitude below 692 km
- MLT drift rate will reverse and stay within requirements limits until early 2022
  - Orbital altitude will degrade and MLT will change until platform de-orbits
  - Terra will not maintain its WRS-2 ground track

Baseline scenario fuel usage prediction

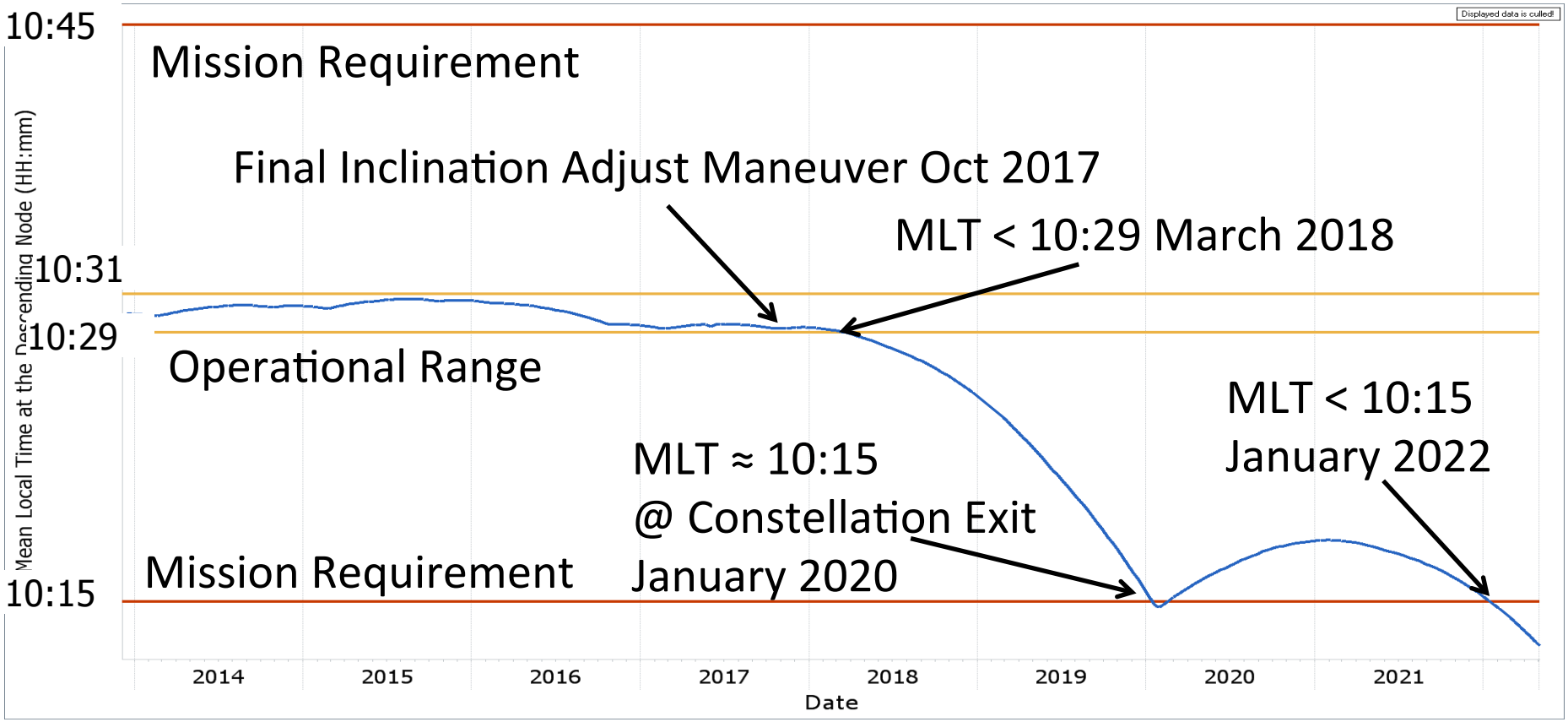


Baseline scenario MLT prediction

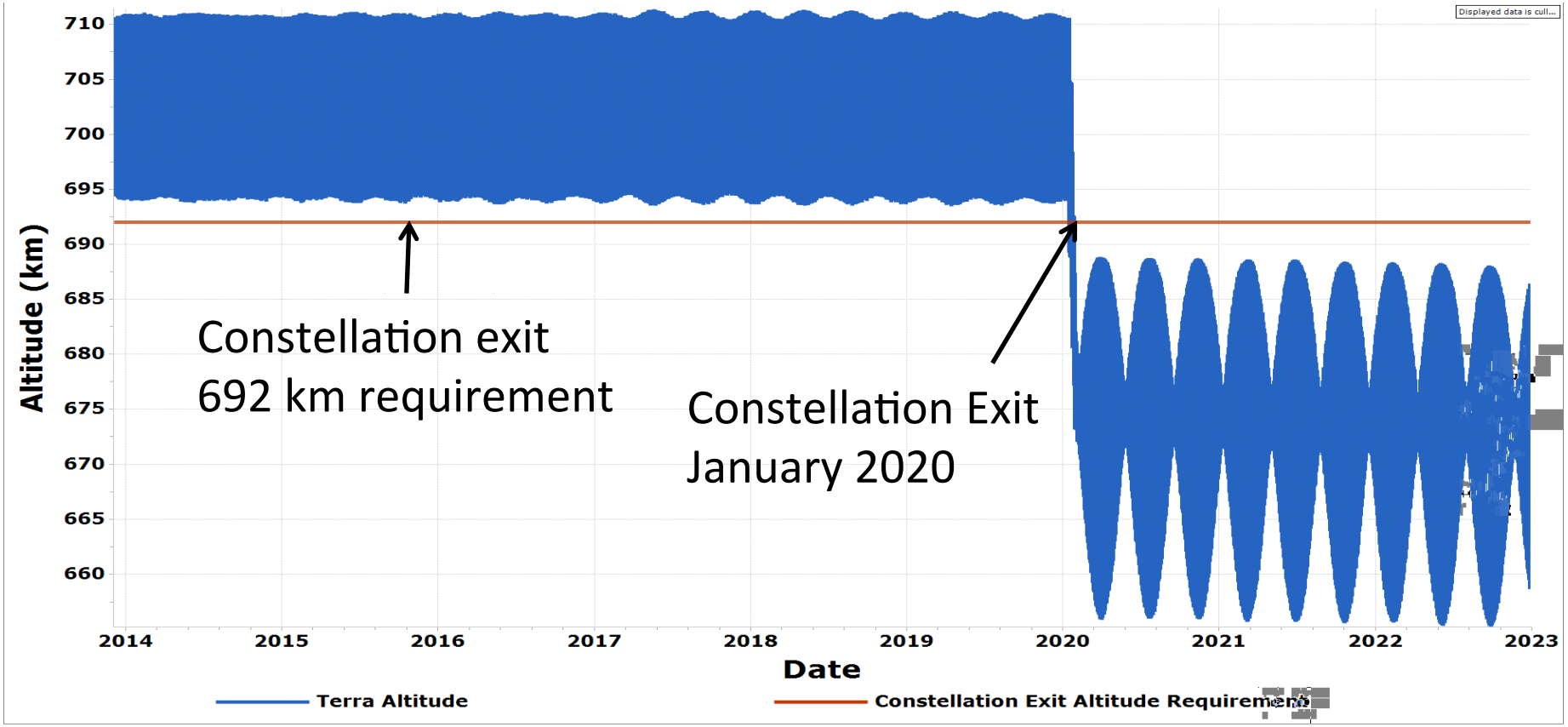


Modified baseline scenario

Additional inclination maneuvers added in the Fall of 2017



Modified Baseline scenario altitude predictions



After constellation exit, Terra will have 689 km maximum altitude and 656 km minimum altitude

Orbit slowly degrades over the next 30+ years until reentry

Altitude impacts

As Terra's orbit decays, instrument swaths and spatial resolution will continually decrease

Instrument	Current		Post-constellation exit	
	Spatial Resolution (km)	Cross Track Swath (km)	Spatial Resolution (km)	Cross Track Swath (km)
MISR	0.275, 0.550, or 1.1	380	0.263, 0.526, or 1.05	364
MODIS	0.250 (day) and 1 (night)	2330	0.239 (day) and 0.96 (night)	2233
MOPPIT	22 (horizontal)	616	21.07 (horizontal)	590
ASTER*	0.015 (VNIR - horizontal) and 0.09 (TIR)	60 (VNIR and TIR)	0.014 (VNIR - horizontal) and 0.086 (TIR)	57.5 (VNIR and TIR)
CERES	20	NA	19.1	NA

Too many scenarios to evaluate in detail

- Maximize time in operational MLT range (10:29 to 10:31)
  - Orbit lowering maneuvers to maintain MLT
- Maximize time in required MLT range (10:15 to 10:45)
  - Exit constellation prior to starting MLT drift
  - Lower orbit below constellation exit criteria
- Maximize time at current altitude of 705km
  - Maintain altitude with DMUs but no more IAMs
  - Drift MLT past 10:15 to ~10:02 then lower orbit
- Maximize mission life to greatest extent possible
- Exit constellation by lowering perigee or apogee only
- Exit constellation sooner to regain MLT time
- Seek Relaxation in constellation requirement from 692 km to 694 km
- Stop all maneuvers (DMU & IAM) and allow orbit to slowly degrade

Next scenario to be examined

Input from Instrument Team Leads has already led to the first refinement in scenario studies

- Relief on 692 km apogee limit means
  - Less fuel needed to exit constellation
    - 2 maneuvers (8 kg fuel) rather than 10 maneuvers (40 kg fuel)
    - Leaves more fuel for other maneuvers
  - Achieve science for a longer period
- Relaxation of constellation exit criteria would delay the date of last IAM and constellation exit burns
  - Ground track and altitude could be maintained until a later date
  - Risk to constellation is higher

Scenario studies and time line

Early estimates of constellation requirement relaxation show ground track maintained until 2023

- Detailed study underway to evaluate this
- Still dependent on approval from Constellation Group
  - Need science input on what alternate studies to evaluate
  - Evaluations will take place over summer
- Finalize Terra Project Science Office's recommendation to FOT in early fall
- FOT will present preferred scenarios to the Mission Operations Working Group meeting in October