GODDARD SPACE FLIGHT CENTER

Terra Status Update including End of Mission Orbit

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MODIS/VIIRS Science Team Meeting
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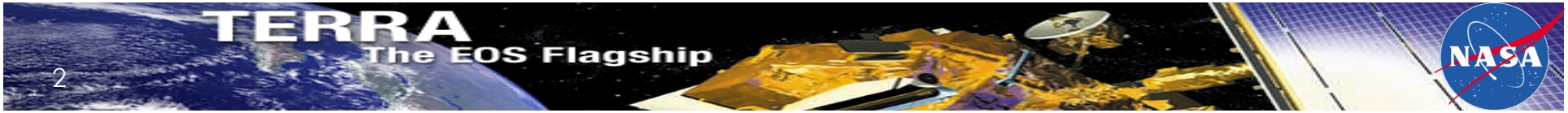
Summary of recent events

Terra completed another successful Senior Review in October 2015

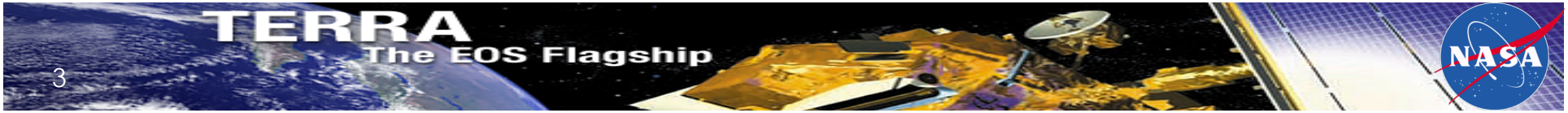
- **Terra is an exemplary mission that offers a tremendous long term data record capable of identifying subtle climate signals**
- Safe hold of the platform in February while performing an inclination maneuver
  - Cause was determined and platform is healthy
  - All instruments recovered without issue
- Terra March Workshop in Boulder discussed impacts on science from crossing time
  - Decision to move forward with request to continue operating Terra at current crossing time until 2021
  - Making plans for a lunar calibration in summer 2017



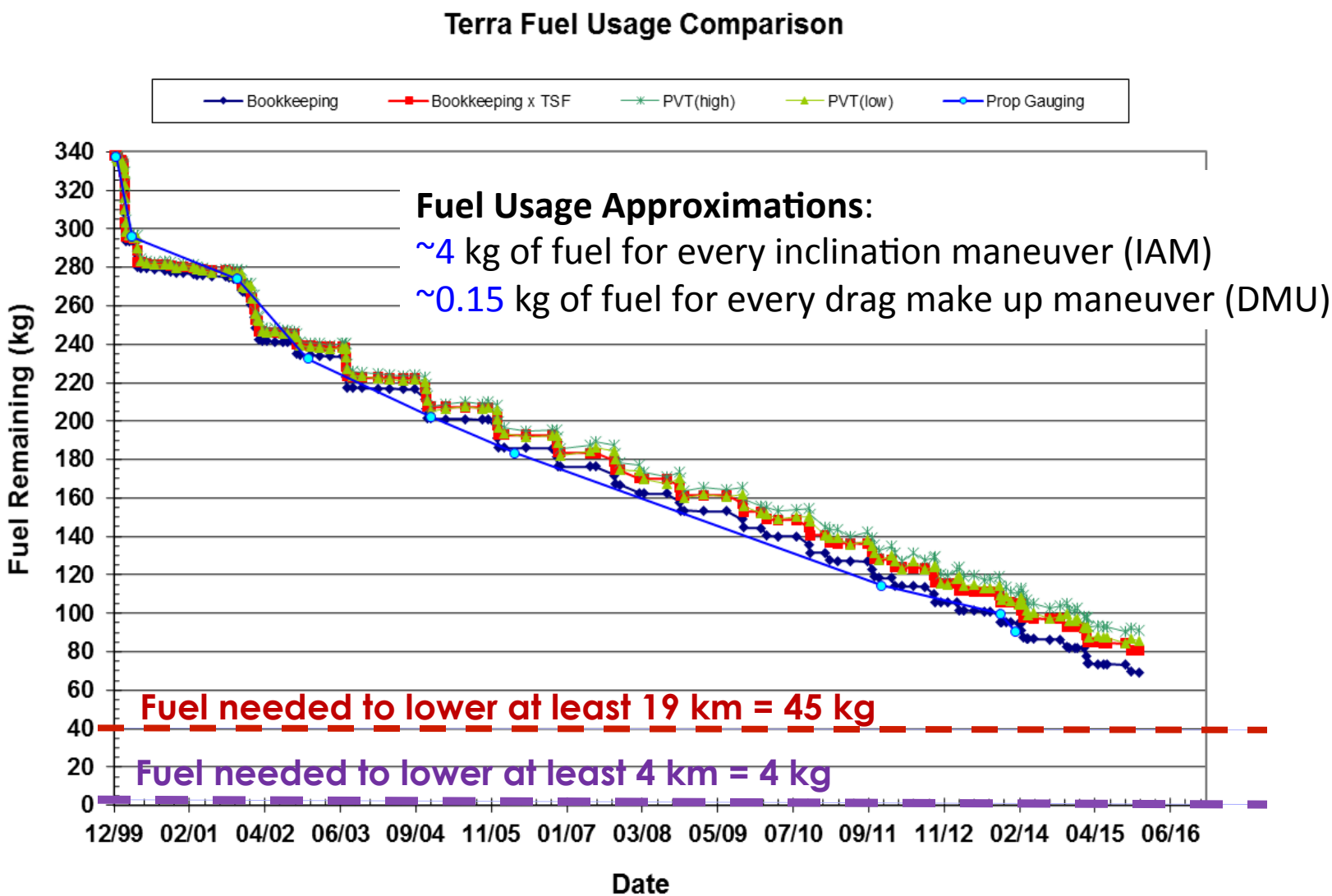
Terra platform and sensors are healthy

Plan is to continue Terra mission for as long as sensors are providing valuable data

- Mission continues to produce important science
- Terra platform and instruments expected to continue operating through 2022
  - Indications are that instruments and platforms will perform past 2022
  - 2022 is when Terra is predicted to cross its 10:15 am crossing time requirement
- Remaining fuel and how to use it is the dominant platform-related factor



Terra's fuel dominates future planning

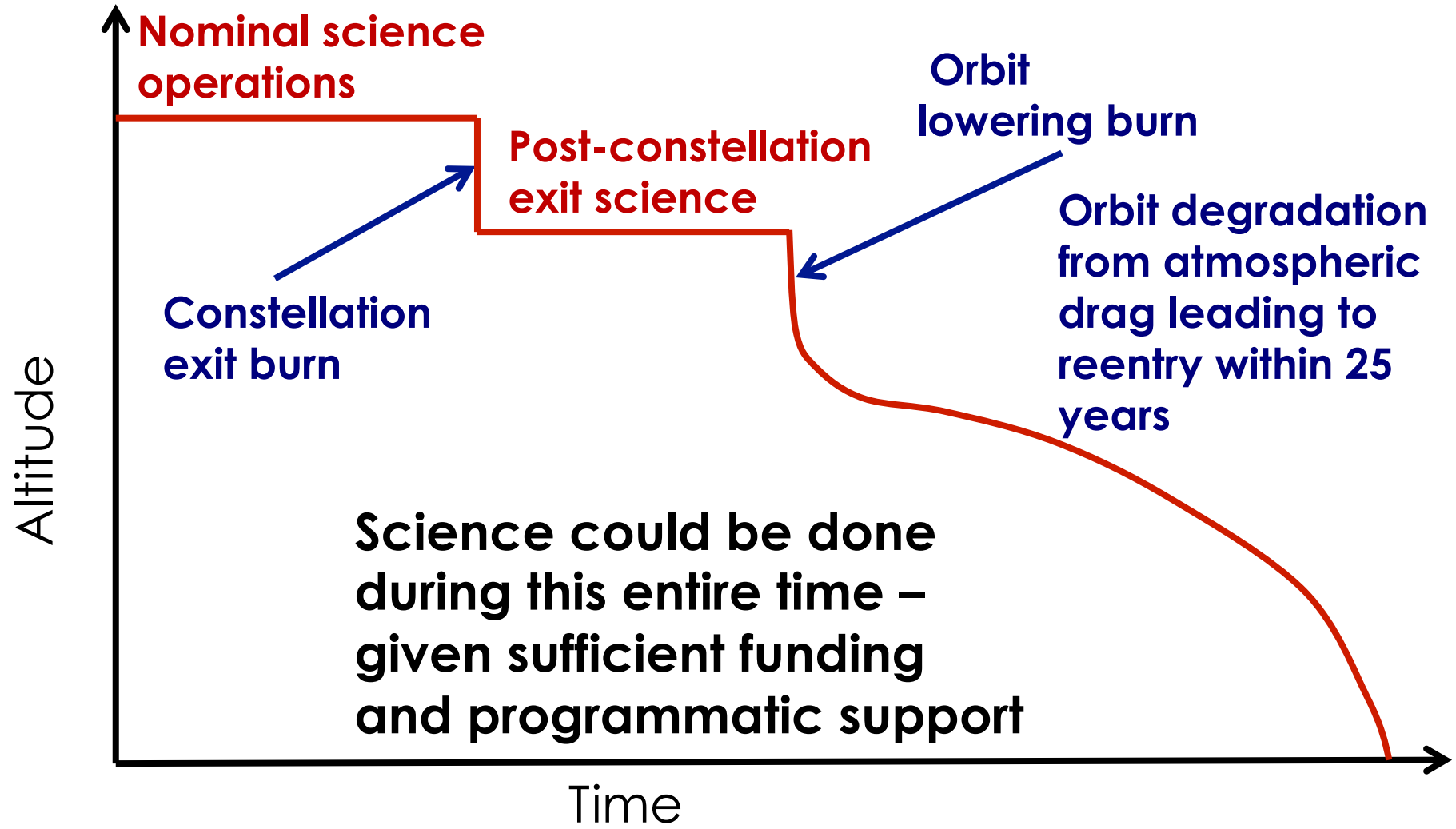


Fuel Usage Approximations:

~4 kg of fuel for every inclination maneuver (IAM)

~0.15 kg of fuel for every drag make up maneuver (DMU)

"Nominal" mission scenario

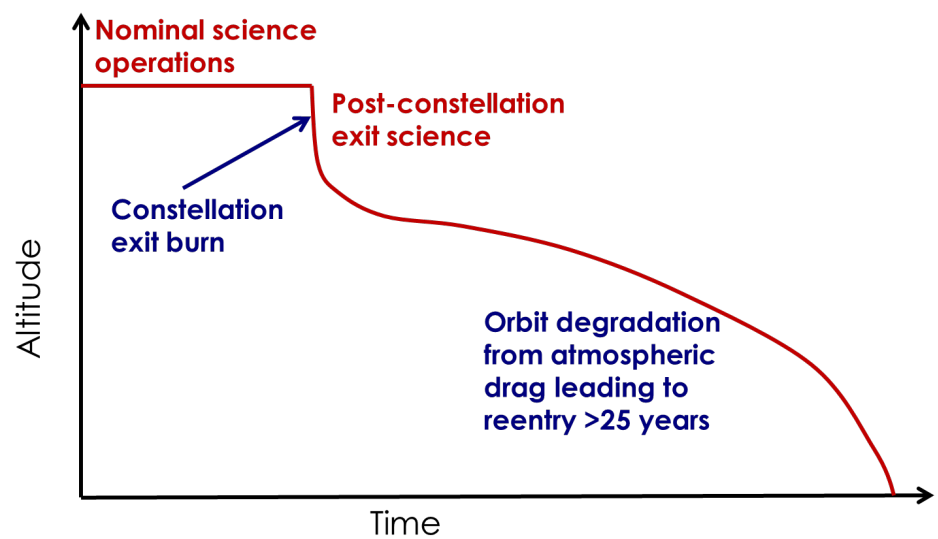


Science could be done during this entire time – given sufficient funding and programmatic support

Terra's scenario (details later)

Terra needed to perform an orbit-lowering burn in 2013 to meet 25-year requirement

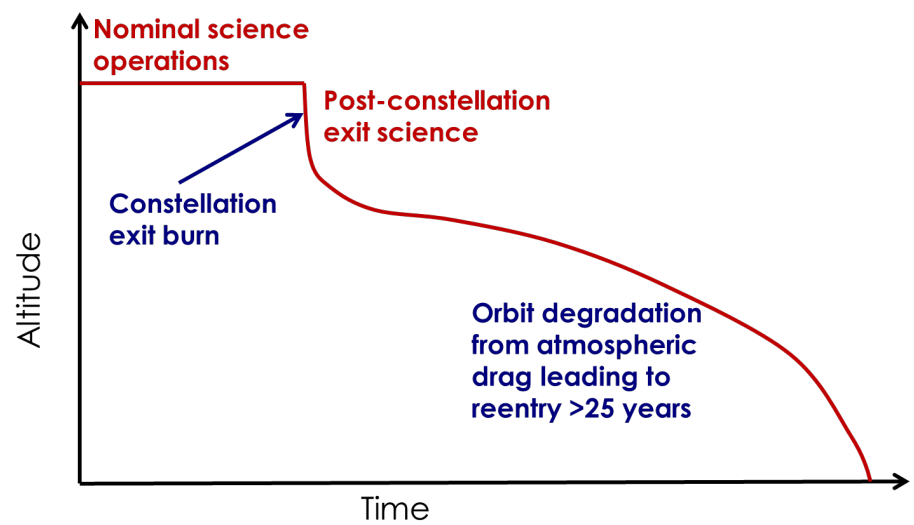
- Earliest predicted re-entry if Terra used all of its fuel today would be after 2045
- Approach for Terra is to continue doing IAMs until the remaining fuel matches what is needed to exit
- Approval of this plan is via a signed End-of-Mission Plan
- Terra does not have fuel for controlled re-entry
- Need sufficient fuel to exit constellation
- Fuel will remain for collision avoidance maneuvers



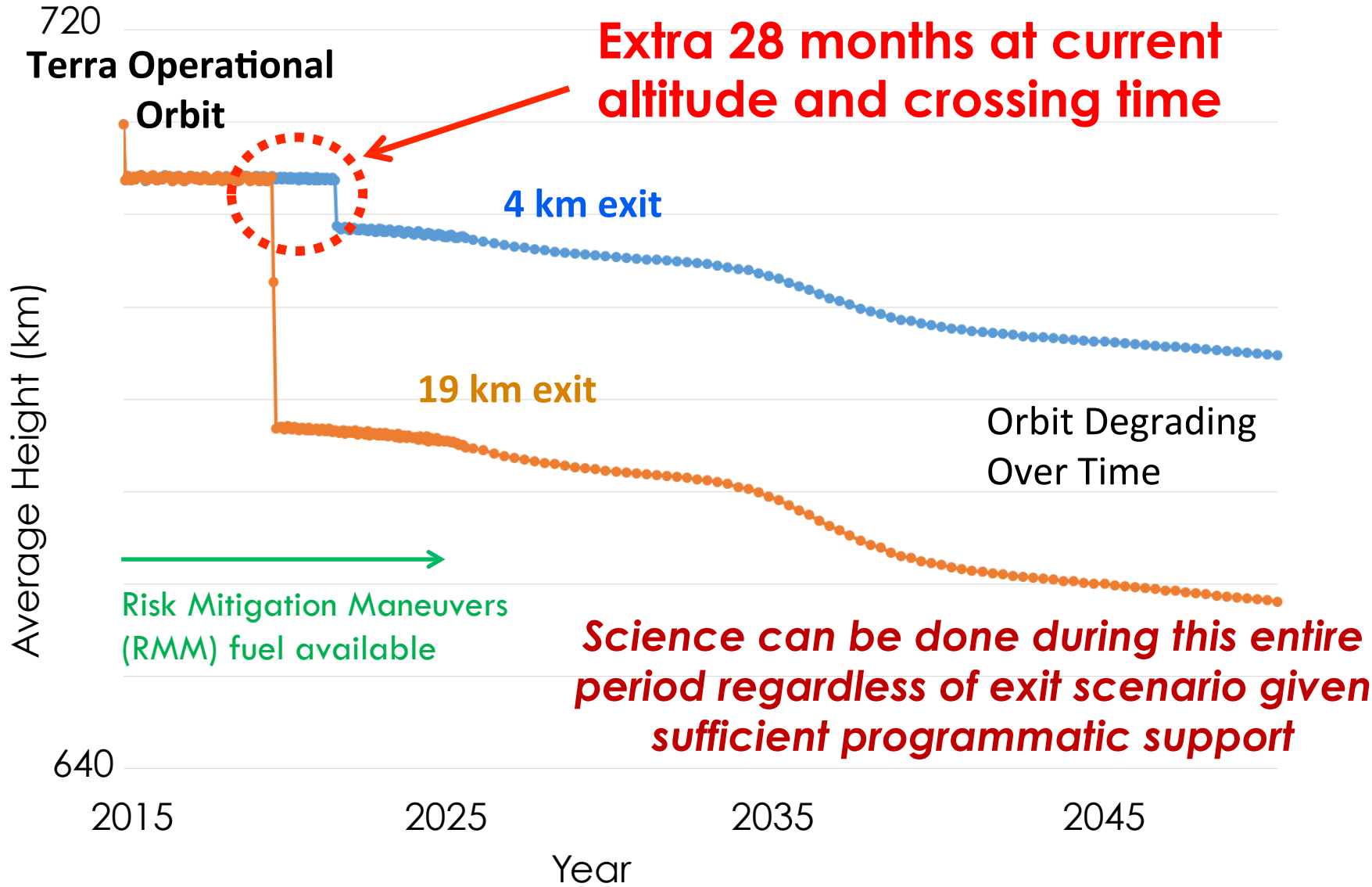
Terra mission length extension

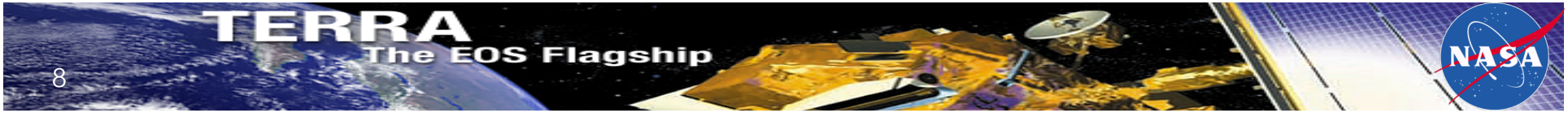
Extending length of Terra mission is highest priority of science & instrument teams

- Lack of follow-on sensors means Terra instruments will continue to be a unique resource for at least 5 years
- Science can be done with Terra data regardless of altitude and crossing time
- Emphasis of Terra science will shift depending upon when and how Terra exits the constellation
- There is no breaking point to science due to changes in altitude or crossing time

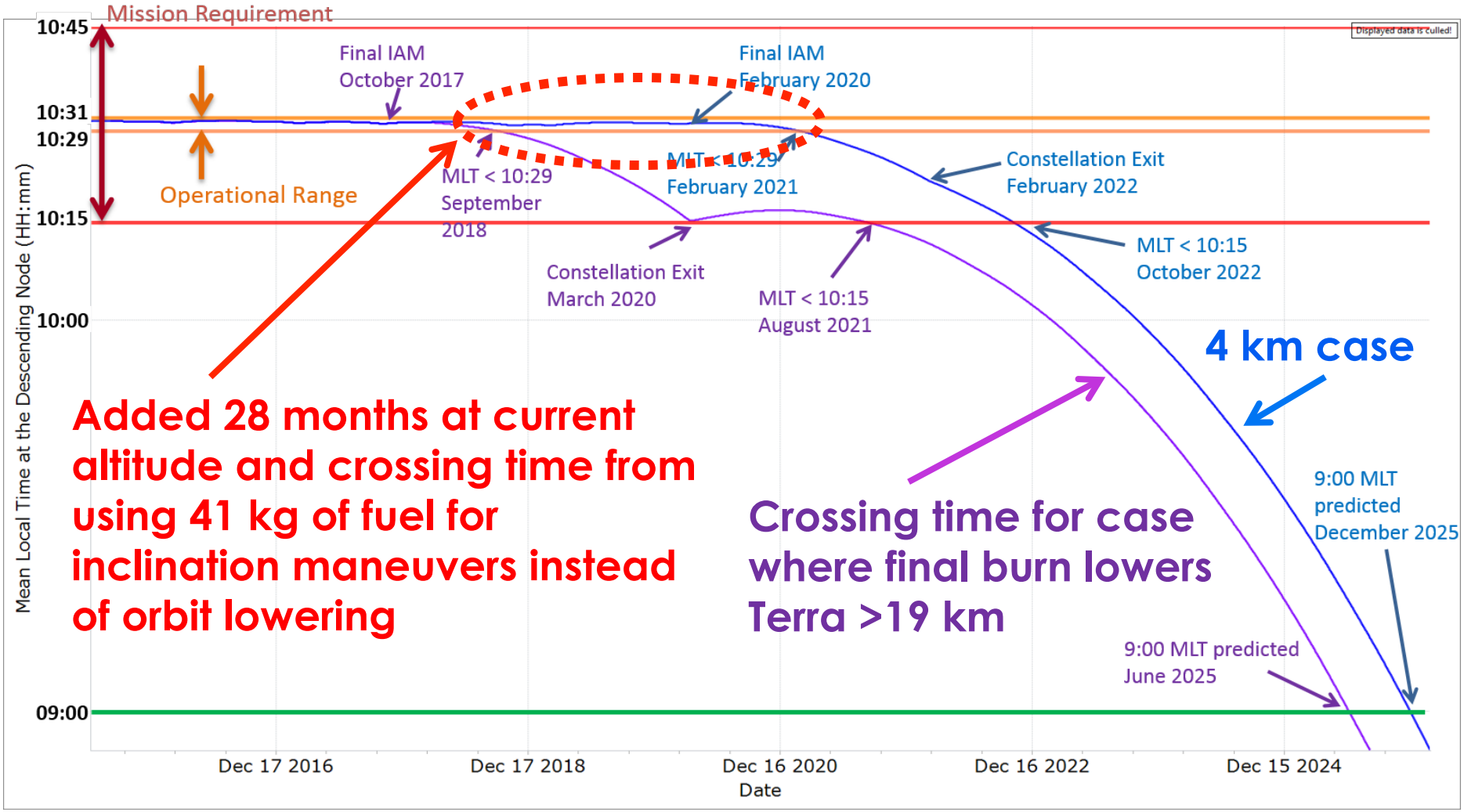


Terra altitude scenarios



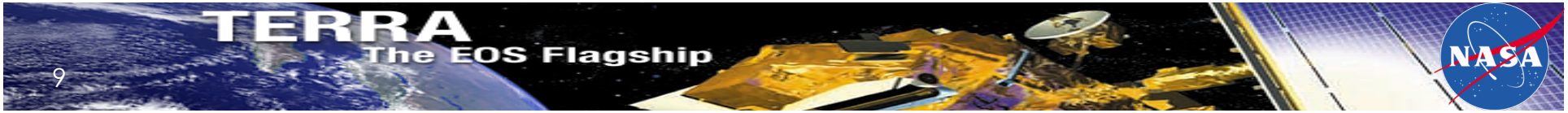


Fuel usage impacts Terra's crossing time



Added 28 months at current altitude and crossing time from using 41 kg of fuel for inclination maneuvers instead of orbit lowering

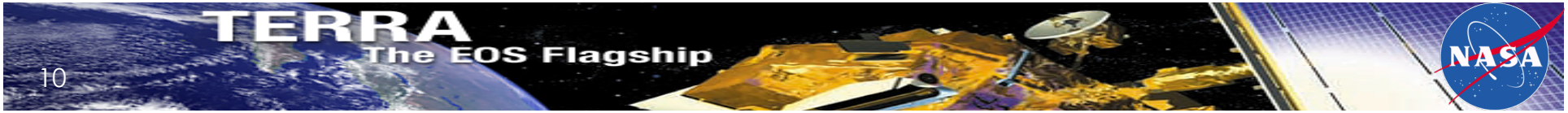
Crossing time for case where final burn lowers Terra >19 km



Terra science

- Terra provides science community with data to study Earth as a system, discover how Earth is changing and explore human interactions with these changes
- Provide answers to “How is the Earth changing and what are the consequences for life on Earth?”
- Ensuring continuation of Terra’s data record makes the data more valuable by creating a record long enough to
  - Gather statistics relevant to the define climate metrics
  - Develop an understanding of our climate system
  - Examine interannual variability
  - Observe trends on the decadal scale

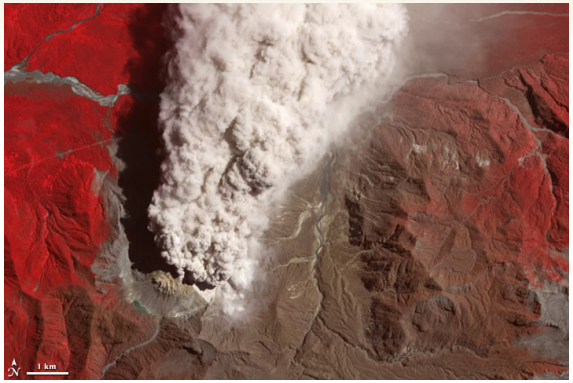
The 4 km exit scenario extends this science record until 2022

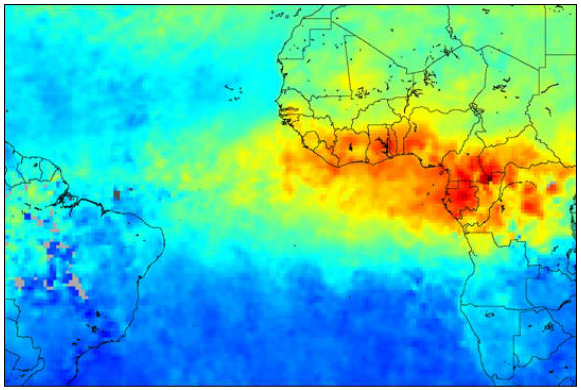


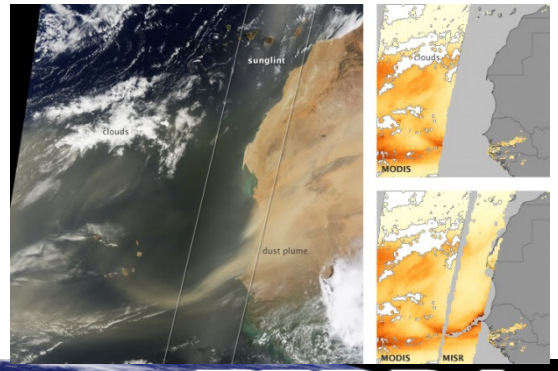
Terra's 16+ years

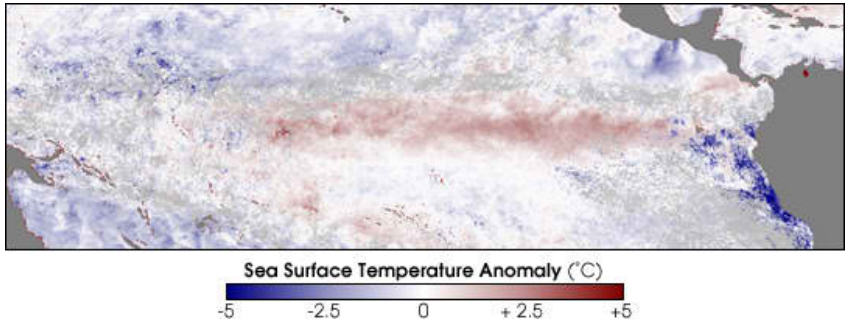
>15 year record changes character of Terra mission from process-oriented to climate-observing

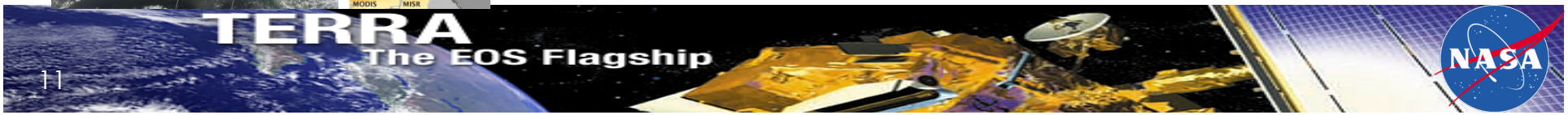
- Longer record increases chance of observing climatically significant events and distinguishing natural variability from anthropogenic change
- Climatic or human-caused variability in occurrences of severe wildfires, dust outbreaks, extreme air pollution, and impacts on air quality of regulatory changes or economic recovery
- 22-year record spans 2 complete solar cycles allowing studies of impact of solar variability



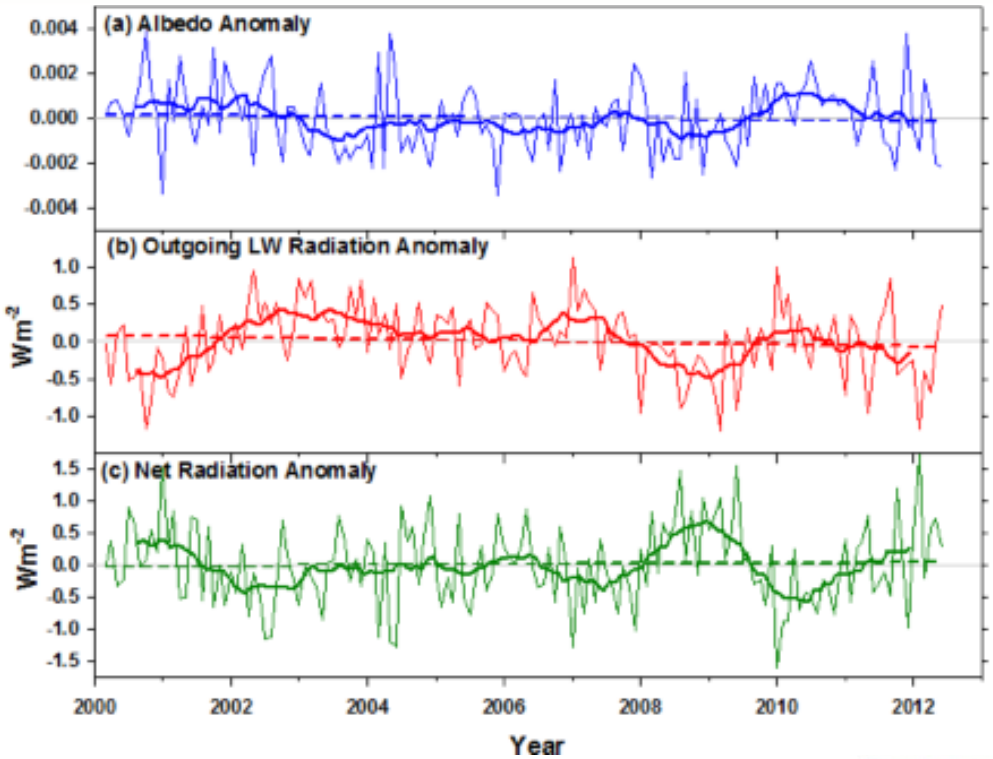




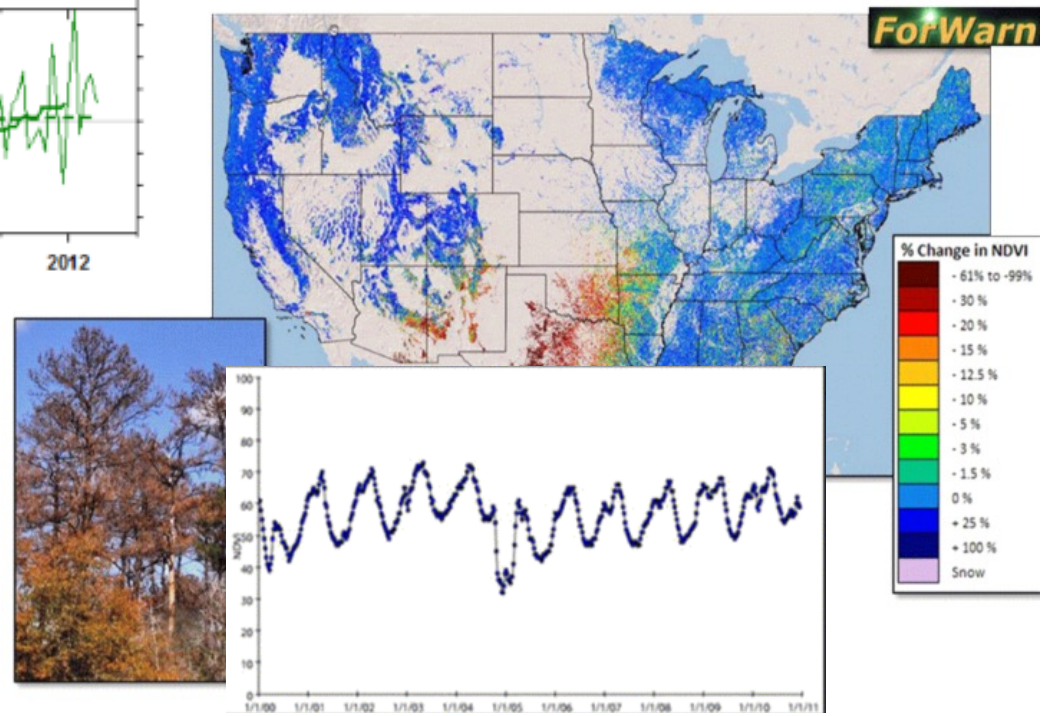




Current data record examples



Deseasonalized anomalies in CERES broadband (a) albedo, (b) outgoing LW radiation, and (c) net radiation. Thin line corresponds to monthly anomalies, thick line is a 12-month running mean

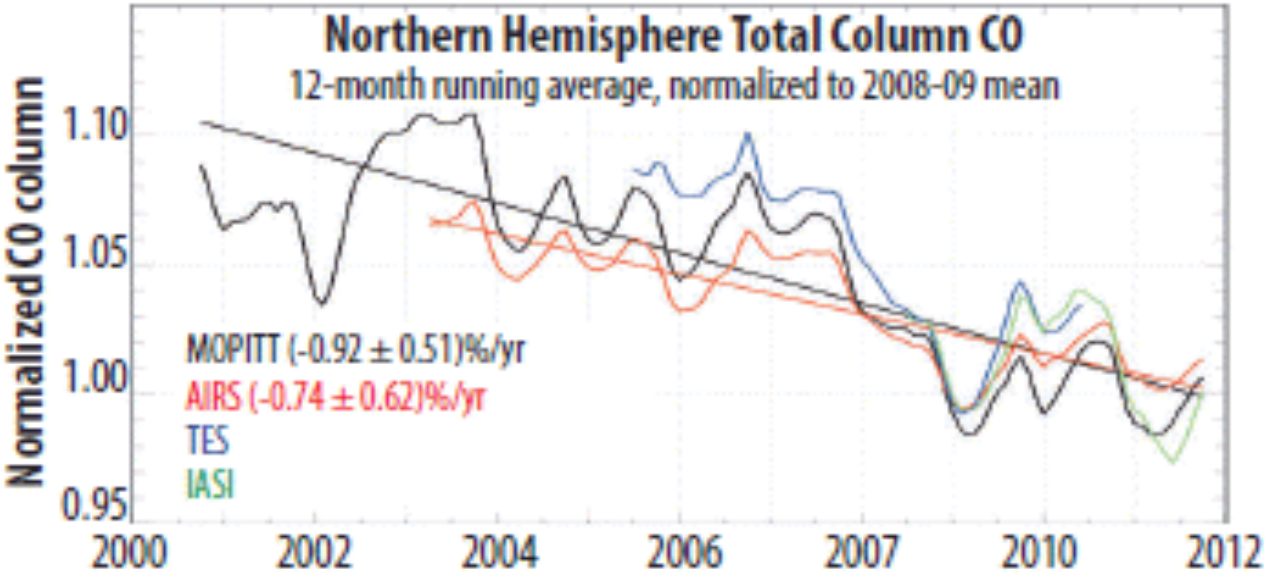


ForWarn has used MODIS NDVI to track forest change providing real-time forest change maps for the continental United States every eight days

Intersensor reference

Terra data provides a standard by which newer missions compare

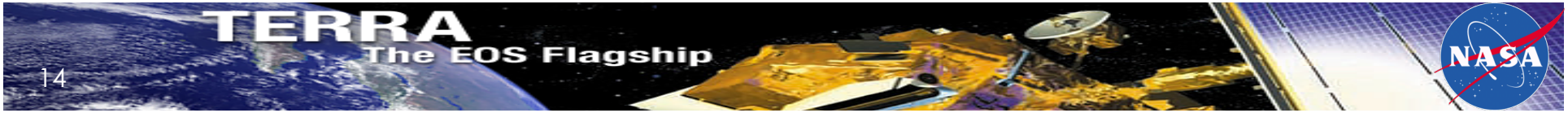
- Proven test bed for new science and improved processing algorithms
- Several planned sensors to become operational from 2019 to 2022



Impacts to Terra science

Changing orbital altitude and/or crossing time has both programmatic and science impacts

- Changing crossing time affects data quality
  - Earlier crossing leads to lower solar elevation, lower reflected energy, poorer signal to noise
  - Lower solar elevation leads to more shadowed data
  - Cloud probabilities change
- Changing orbital altitude changes spatial coverage
  - New geometric processing algorithms may need to be developed
  - Decrease spatial coverage (swath width)
  - May cause gaps in spatial sampling



Time series impact is the real issue

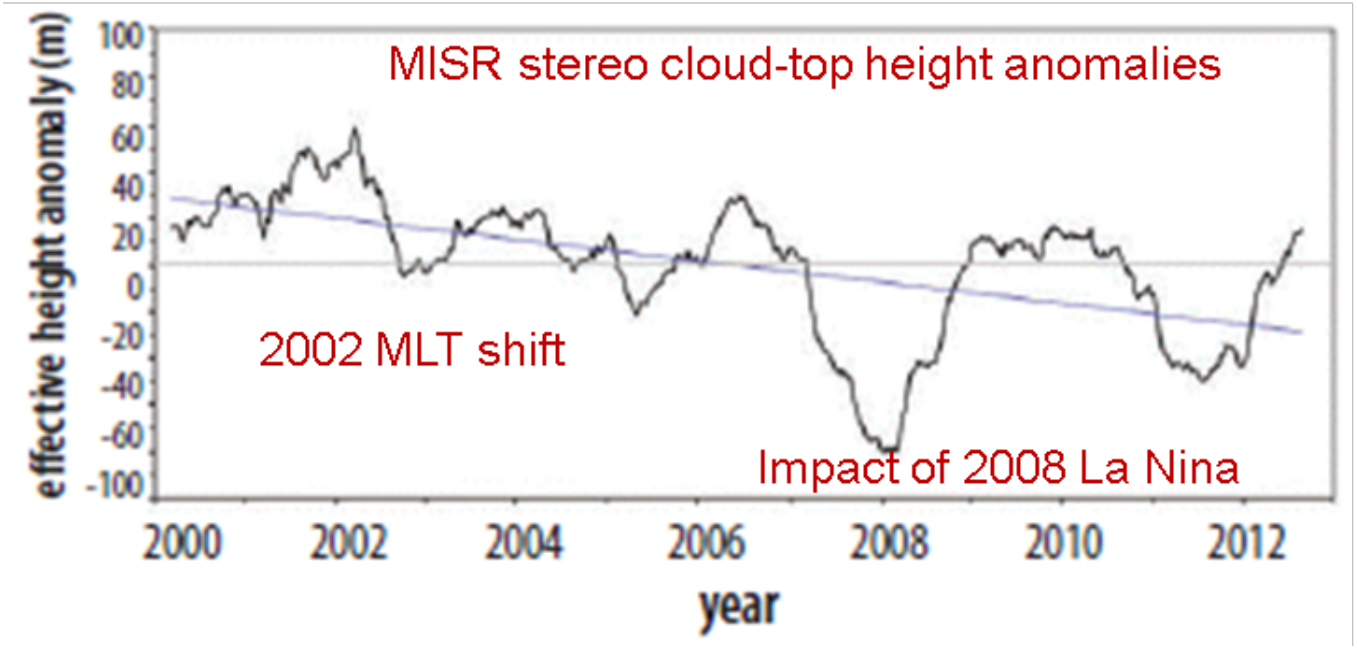
The length and quality of the Terra data record makes it suitable for time series analyses

- Most physical parameters have a **time dependence**
  - Temperature changes during the day
  - Cloud distributions
- Goal in time series analysis is to detect change
  - Change in MLT can cause changes in that parameter on the **order of or larger** than the change that is trying to be detected
  - Corrections for crossing time can be developed but **add uncertainty** to the retrievals

Initial crossing time change - Cloud example

10:45 to 10:30 crossing time change coincided with noticeable changes in data records

- Change in cloud climatology could be real or due to crossing time (MLT) change

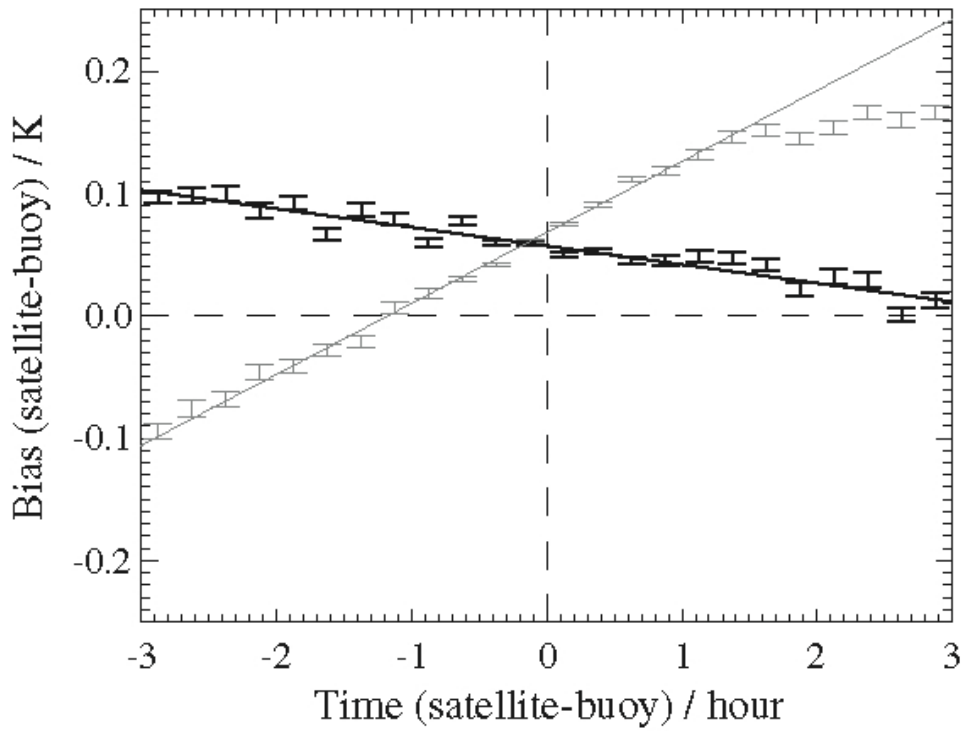


- Assessing impacts on time series is more difficult

MODIS SST example

Mean difference between satellite-based sea surface temperature and buoy retrievals

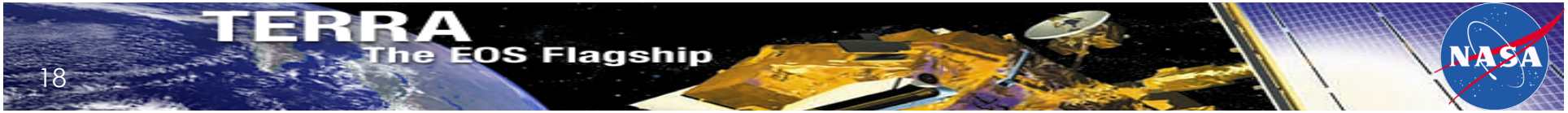
- Shown to change about 0.1k/hr
  - Varies with location
  - Caused by diurnal heating of the ocean
  - Data were for an equator crossing time of 10:00 so applicable to Terra.
- Drift of 15 minutes gives an average change in the global SST of 0.025K
  - Order of magnitude greater than the annual stability requirement for climate records
  - Corrections could be made but uncertainties would be comparable to anticipated climate change signals



Terra March Workshop Conclusions

Workshop summarized science impacts related to crossing time

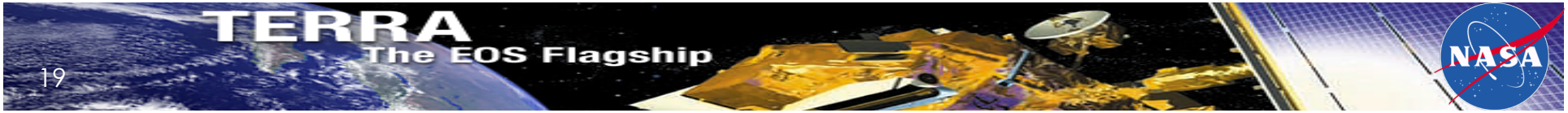
- Morning Terra record is currently unmatched in quality and duration
- No planned successors in morning orbit for several instruments
- Terra will provide excellent data for meeting science objectives regardless of changes in altitude or crossing time
- Climate trends can be better distinguished from interannual variability as data record approaches 20 years
- 15 minute changes in Terra crossing time impacts science causing
  - 1% change in cloud fraction for boundary layer stratocumulus
  - 1K change in mean land surface temperature
- 4-km exit strategy ensures continuation of current pattern of global sampling until 2022
- **Maintaining current crossing time for as long as possible provides clearest climate-relevant data set**



Terra Crossing time Panel Conclusions

Utmost importance to continue this data record while the Terra instruments are performing nearly optimally

- Significant scientific value to be gained by extending the mission at the current 10:30 crossing time for as long as possible
- Additional 28 months of observations at the 10:30 crossing time will be invaluable to climate trend studies
- A change in the crossing time would mark the end of Terra's "climate quality" data record for trend analysis
  - Magnitude of crossing time impact would be equivalent to the magnitude of the trends expected from climate models
  - Ability to separate a climate trend from the climate's natural variability is strongly dependent on the length of the observational record
- Likely be several decades until the science community can again build upon a 16+ year climate record from another continuously operating platform with similar capabilities



Terra recommending 4-km exit fuel use plan

Terra will continue inclination maneuvers to maintain current crossing time until Feb. 2020

- Last inclination maneuver in Feb. 2020 leads to crossing time drift after that point
  - Science gains 2 ½ years of constant crossing time data beyond the current Oct. 2017 end of IAMs
  - Crossing time drifts to 10:15 am in Aug. 2022
- Altitude lowering by at least 4 km in Aug. 2022
  - Any fuel remaining would only support collision avoidance
  - Orbital altitude degrades and crossing time changes after this point until platform de-orbits
  - Terra does not maintain its WRS-2 ground track
- Still requires approval of NASA Headquarters

March Workshop also discussed lunar calibration

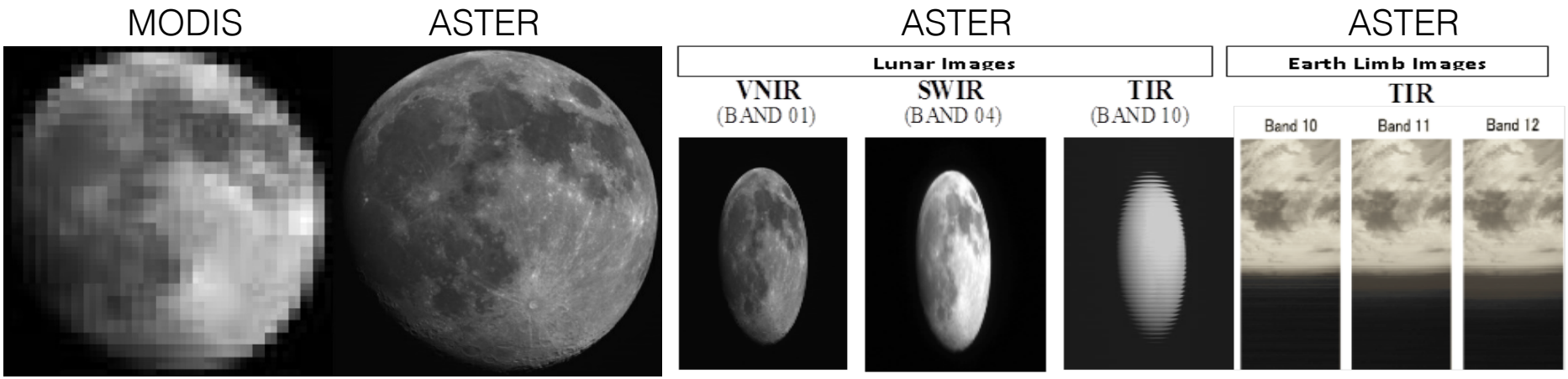
Summer 2017 offers a favorable view of the moon similar to that from 2003

- ASTER team noted the lunar phase, nutation, and libration from April 2003 nearly matches what would occur in July 2016
  - Could have supported a July 2016 maneuver
  - Discussion of fuel usage strategy delayed a decision for too long
- Team has decided to do the deep space calibration in summer 2017 – regardless of decision on fuel burns
- Planning is underway to implement the maneuver
  - Flight operations is completing procedures
  - Project office is gathering the paperwork needed
  - Will likely be a Goddard-based review including NASA HQ

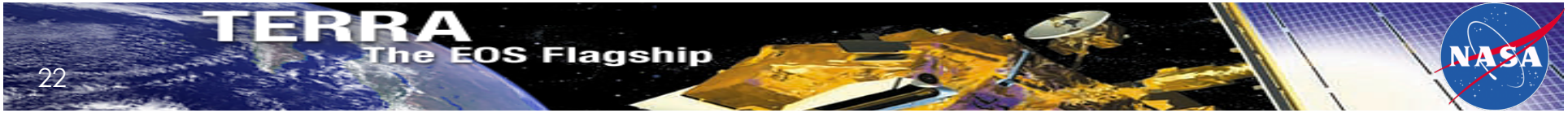
Summary

Next 18 months will be an exciting one for the Terra project

- Another Senior Review process beginning in December
- Decision likely on Terra's fuel use recommendation
- Planning and implementation for Terra's flip to see the moon



Note: Images are from DSC #2 (LDSC) which took place on DOY 2003/104.



Backup

Impacts to L1

Many of the L1 product generations will require modification

- Geometric corrections will require updates
  - Band-to-band registration
  - Camera to camera registration
  - Geolocation processing
- Drift from WRS will be an annoyance but not a major impact
- Straightforward modifications
- Problem is that many of the original product developers have moved to other projects
- Need to determine whether teams can absorb L1 processing changes in their current budgets

Impacts to L2 product generation

Changes to L2 product generation are not needed when crossing time changes

- Shifts in crossing time affect interpretation and use of Terra data products
  - Corrections needed for diurnally varying products
  - Creates confusion between real change versus MLT-induced changes to data quality, data sampling, or changing position of sun glint
- Sun angle changes will impact data quality near poles
- There is science value (e.g., data assimilation) in collecting data at other crossing time

Impacts to L3 product generation

L3 products should see the highest impact from crossing time change (and WRS drift)

- L3 processing should not require modification to account for MLT change
  - L3 involves multi-scene combinations
  - Crossing time change will not affect the approach to combining data sets
- Results can see significant impacts
  - See earlier cloud example
  - Drift in crossing time will affect statistics of spatial scenes used in processing
  - Change in crossing time will change the solar geometry of the scenes

How to address necessary processing changes

Cost and schedule question

- Are modifications to L2 processing anticipated?
- Can code modifications be absorbed within current funding profiles?
  - If not, how best to address the funding issue?
  - Can this be addressed through ROSES?
- What is the time line for incorporating changes?
  - Wait until drift is beginning or anticipate drift?
  - What is the process for updating new code?