

Impact of Terra and Aqua Drifting Orbits on MODIS Calibration

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Acknowledgements:

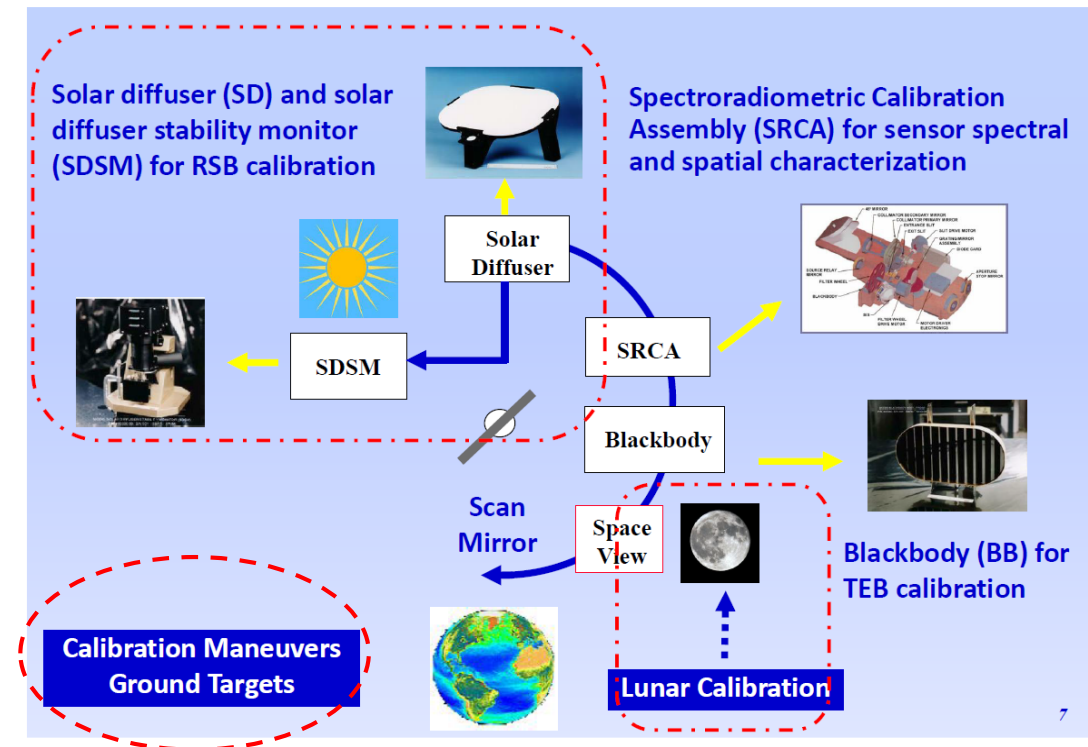
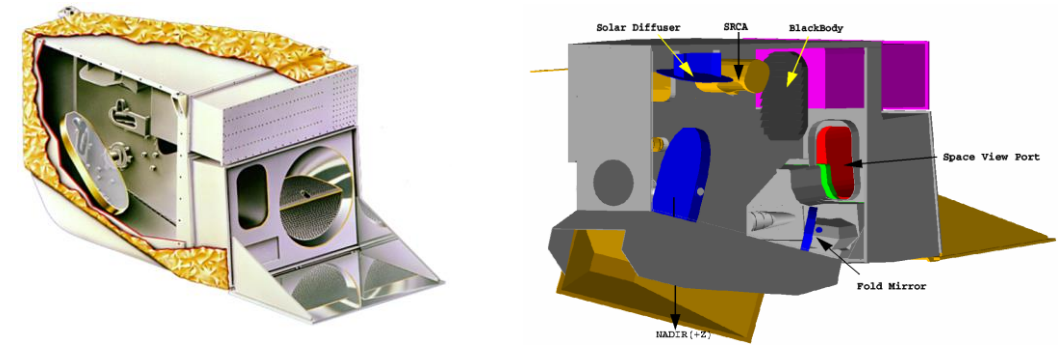
Terra and Aqua Flight Operation Teams (FOT), NASA GSFC
MODIS Characterization Support Team (MCST)

Outline

- **Background**
 - MODIS and Its On-orbit Calibration
 - Terra and Aqua Orbits
- **Impact of Drifting Orbits On MODIS Calibration**
 - Reflective Solar Bands Calibration
- **Strategies**
- **Summary**

Background – MODIS On-orbit Calibration

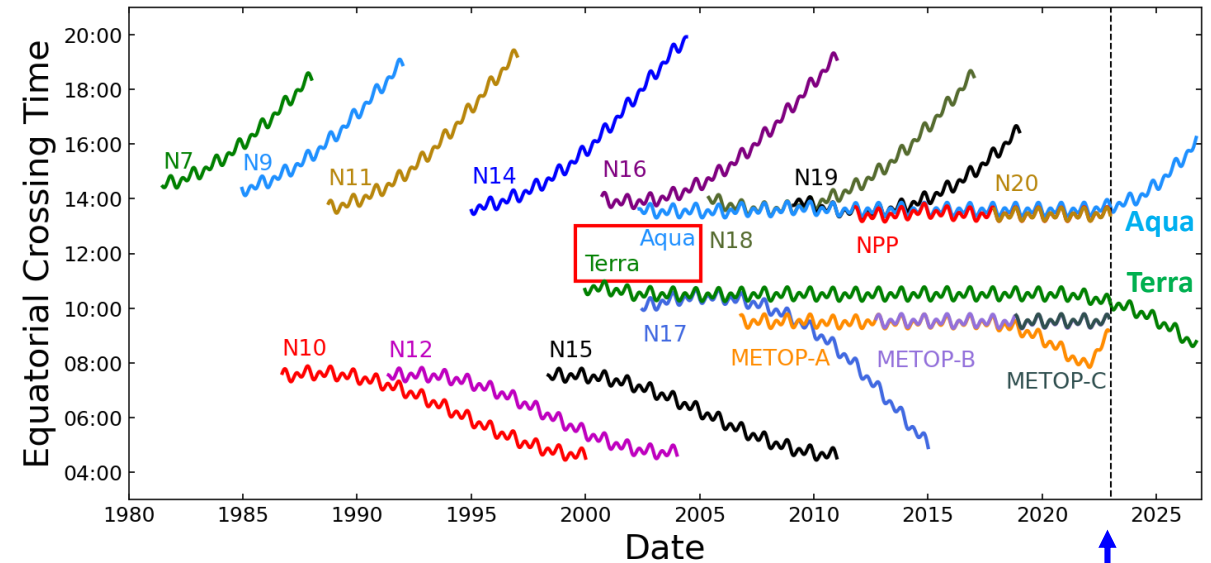
- **MODIS – a key instrument on Terra and Aqua spacecraft**
 - Terra: launched on Dec 18, 1999
 - Aqua: launched on May 4, 2002
 - 20 RSB (VIS/NIR/SWIR) and 16 TEB (MWIR/LWIR): 0.41 – 14.4 μm
- **MODIS on-orbit calibration**
 - Solar diffuser (SD)
 - Solar diffuser stability monitor (SDSM)
 - Blackbody (BB)
 - Spectro-radiometric calibration assembly (SRCA)
 - Lunar observations (Moon)
 - Ground targets (Dome C, DCC, SNO, desert sites, ocean targets, ...)



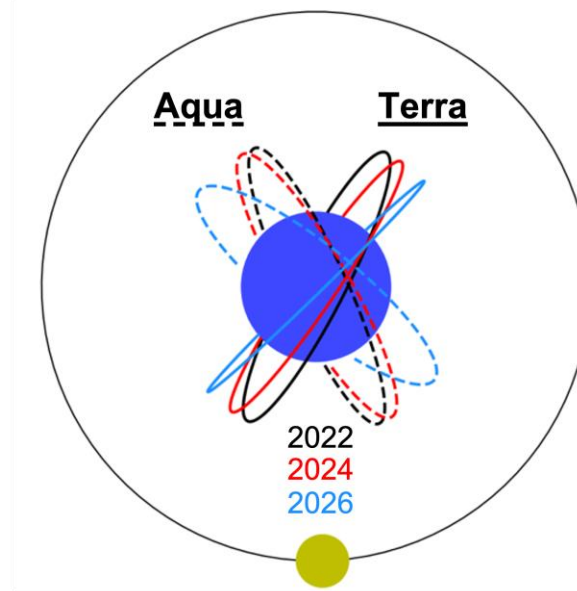
Background – Terra and Aqua Orbits

- **Terra and Aqua orbits**

- Terra and Aqua have been kept at stable equatorial crossing times (10:30 and 13:30, respectively) for most of their mission lifetimes.
- Terra
 - February 2020 – End of regular IAMs
 - October 2022 – Constellation exit maneuvers (CEM), end of regular DMUs, and start of free orbit drift
- Aqua
 - March 2021 – End of regular IAMs
 - December 2021 – End of regular DMUs and start of free orbit drift
- **Going forward, orbit maintenance will stop, and the orbits will drift to earlier (Terra) and later (Aqua) equatorial crossing times.**



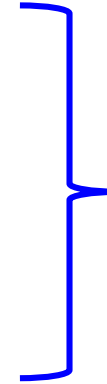
Jan. 1, 2023 when we are projecting the orbit forward



Impact of Drifting Orbits On MODIS Calibration

- **Gradual impact on RSB calibration**

- SD calibration
- SDSM calibration (similar to SD calibration)
- Lunar calibration
- Current approaches of using ground targets



to be addressed here

- **No direct impact on TEB calibration**

- BB (internal calibration source) is used on a scan-by-scan basis
- Potential (minor) impact on crosstalk correction coefficients derived from lunar observations (to be closely monitored) - *not discussed here*

- **Impact on geometric calibration (*not covered here*)**

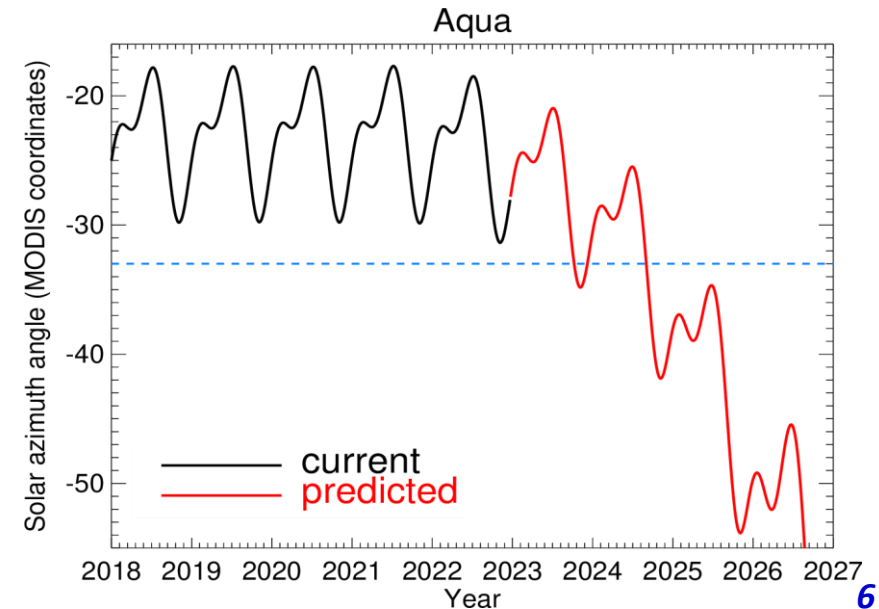
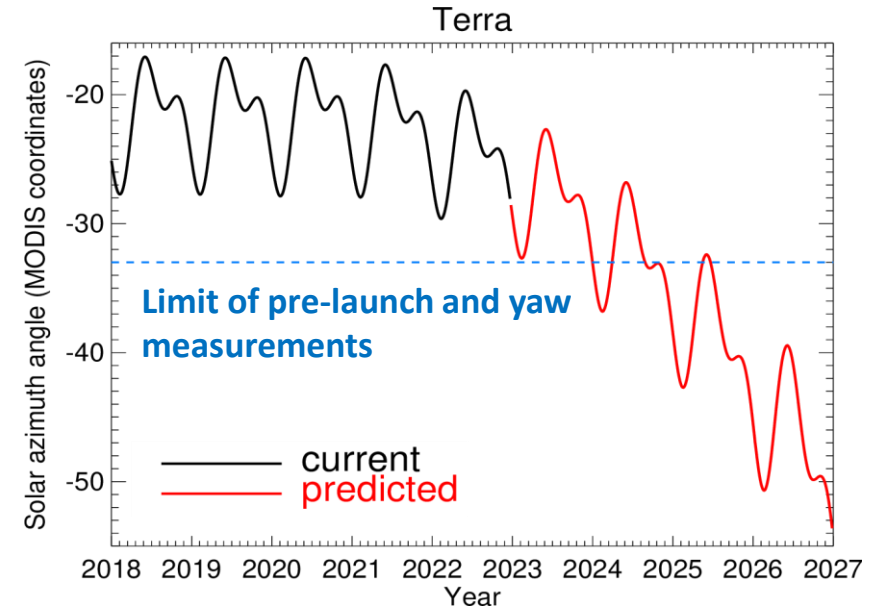
Impact of Drifting Orbits – SD Calibration

RSB Calibration Coefficients (m_1)

$$m_1 = \frac{BRF_{SD} \cos \vartheta_{SD} \Delta_{SD}}{dn_{SD} d_{ES}^2} VF_{SDS}$$

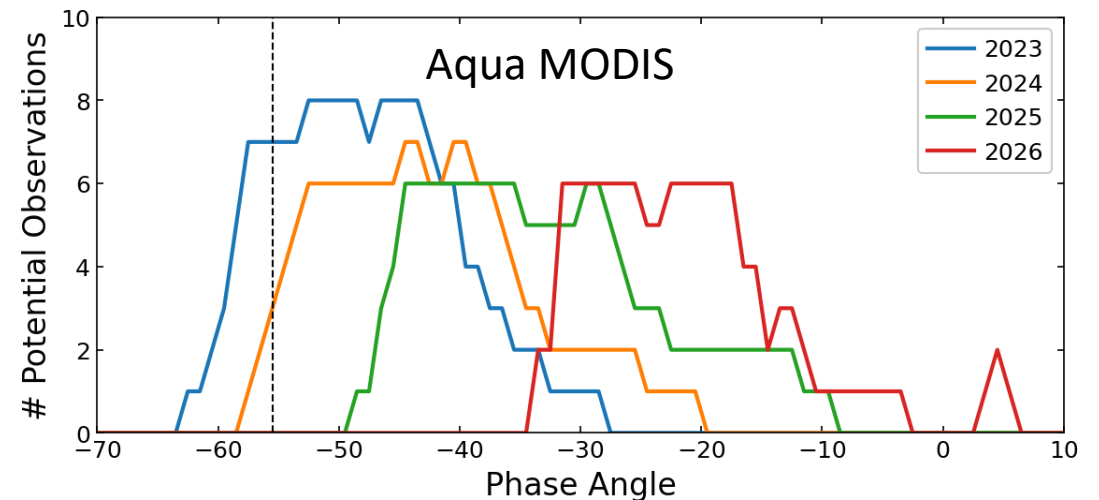
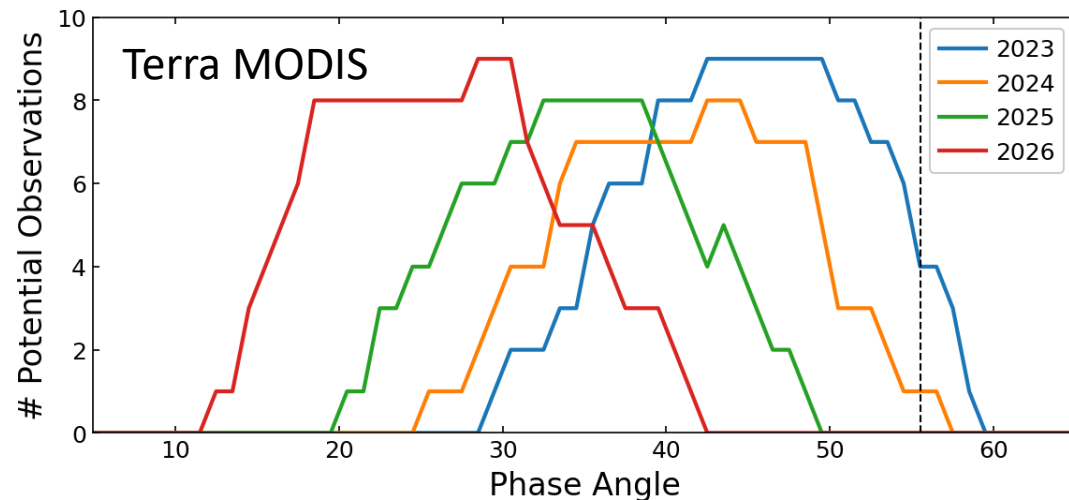
SD **BRF** characterized during pre-launch testing and screen **VF** characterized during yaw maneuvers.

- Solar azimuth angles used for SD calibration (sweet-spot centered at fixed elevation angle of 12.5°) have been gradually shifting as orbital inclination changes.
- Solar angles will exceed (in ~ 2024) the limits of the known SD BRF and SD screen vignetting function determined from pre-launch and on-orbit yaw maneuver measurements.
- Solar angle to the SD surface also drifts in time away from nominal values; number of scans with fully illuminated SD will likely decrease gradually.



Impact of Drifting Orbits – Lunar Observations

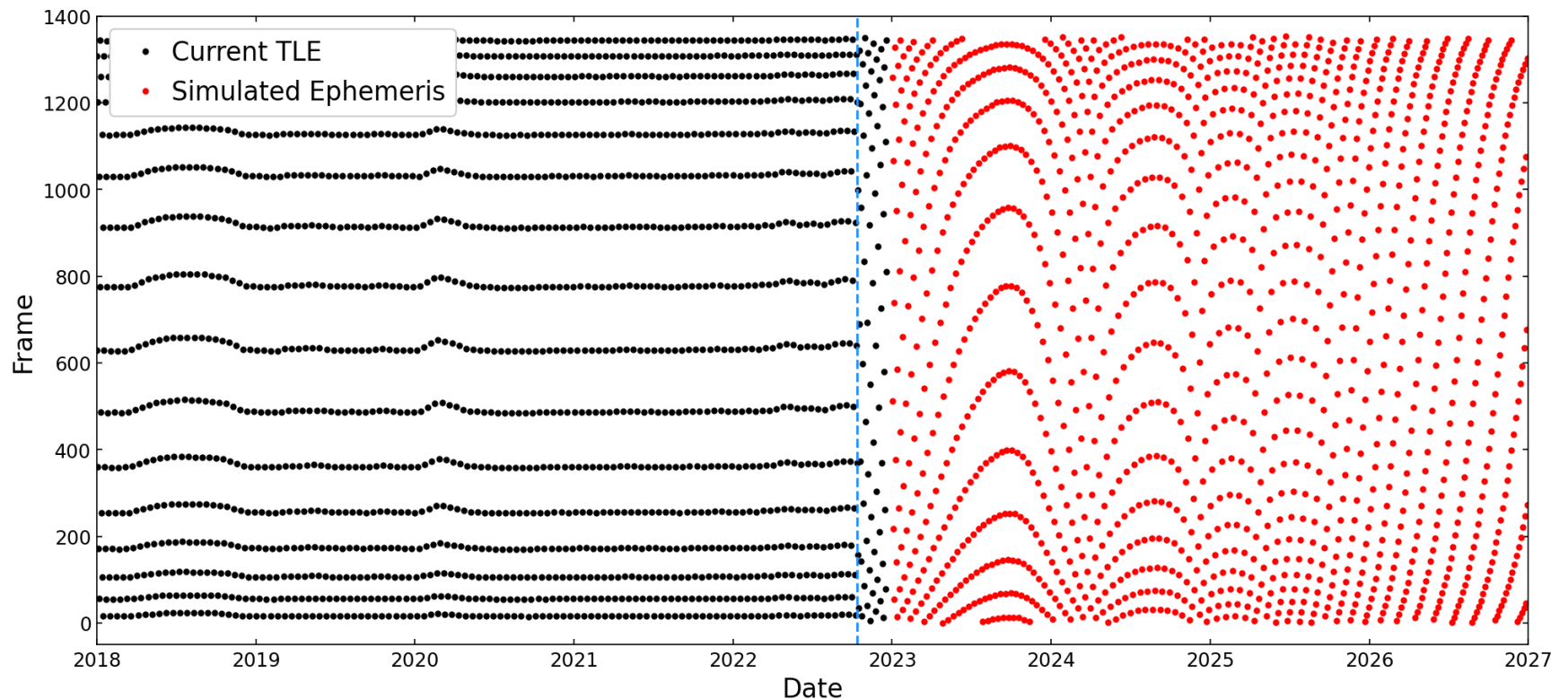
- Nominal phase angle (PA) range for MODIS lunar observations: 55° to 56° (Terra) and -55° to -56° (Aqua)
- With drifting orbits, the select nominal PA range cannot be maintained in order to keep similar number of lunar viewing opportunities and shifts gradually toward a full Moon observation.
- Potential impact (small) on lunar calibration due to use of different lunar PAs; current lunar model uncertainty could be up to 1.0% (TBC) among different PAs.



The histograms are grouped into 1-degree bins and show the number of lunar cycles with observations in that phase angle range

Impact of Drifting Orbits – Use of Ground Targets

- Immediate impact on the view angles (data frame) at fixed Earth scene targets, e.g. the pseudo-invariant desert targets used in RSB stability monitoring and RVS calibration.
 - Frame repeatability of desert data was significantly reduced due to orbit drift.
- Solar angles at times of desert observations also slowly drift with orbit inclination drift.
 - Need to verify the accuracy of semi-empirical BRDF model at these extended solar angles.



Frames (view angles) of Lybia-4 observations by Terra MODIS (historical and **predicted**)

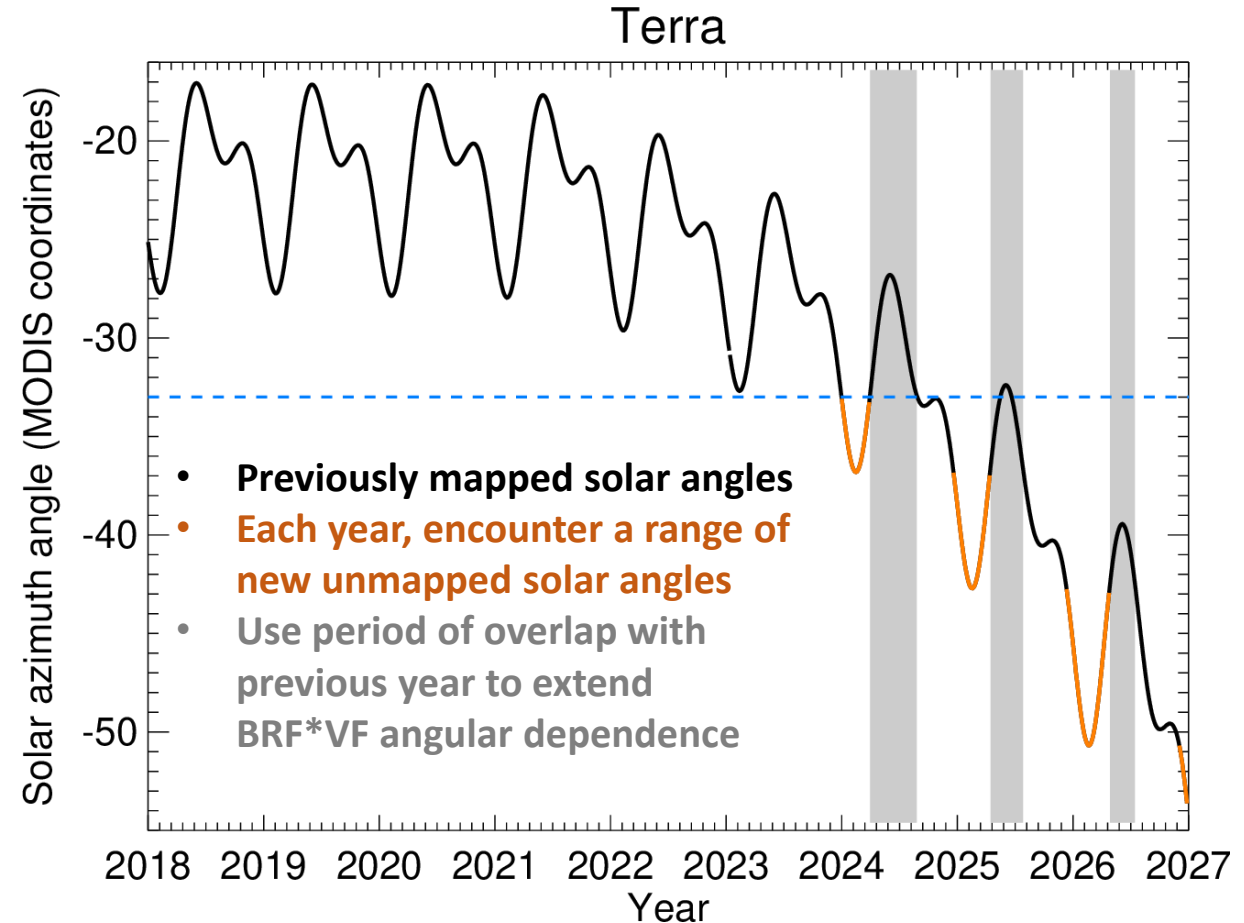
The blue dash line is the time of the Terra CEM in October 2022

Strategies

- **MCST has been actively evaluating potential impact due to drifting orbits of Terra and Aqua spacecraft on MODIS calibration in recent years, and developing alternative approaches and strategies to mitigate the impact, including those to be applied to**
 - SD calibration (similar strategies could also apply to SDSM calibration)
 - Lunar calibration
 - Use of ground targets
- **New opportunities**
 - Opportunities for new science (*not discussed here*)
 - *Terra, Aqua, Aura Drifting Orbits Workshop (Nov 1-2, 2022)*
 - *Terra's Lower Orbit Virtual Community Forum (Dec 8, 2022)*
 - Direct calibration inter-comparison of Terra and Aqua MODIS via near simultaneous nadir overpasses (SNO) – work is underway

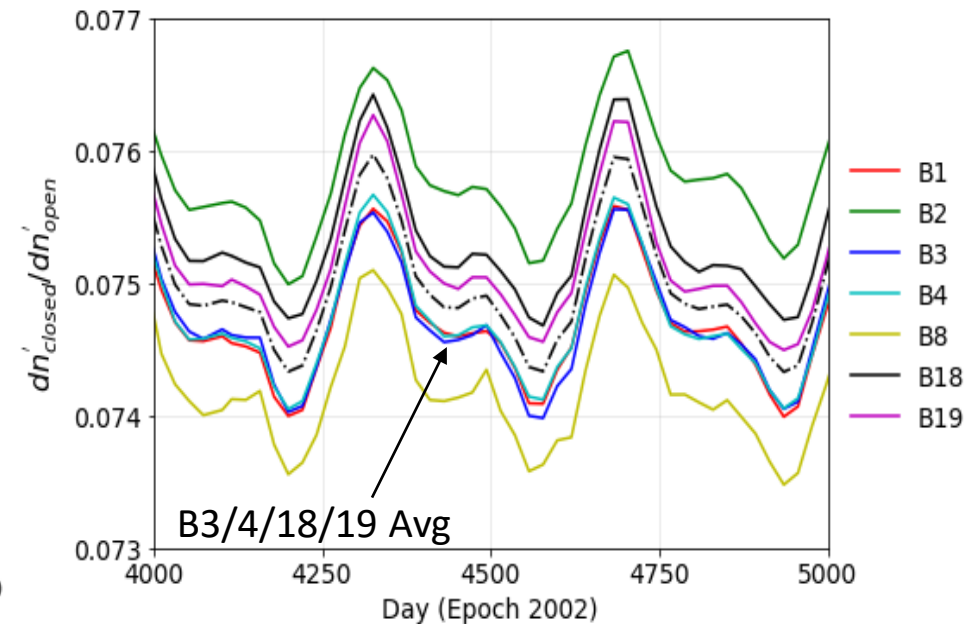
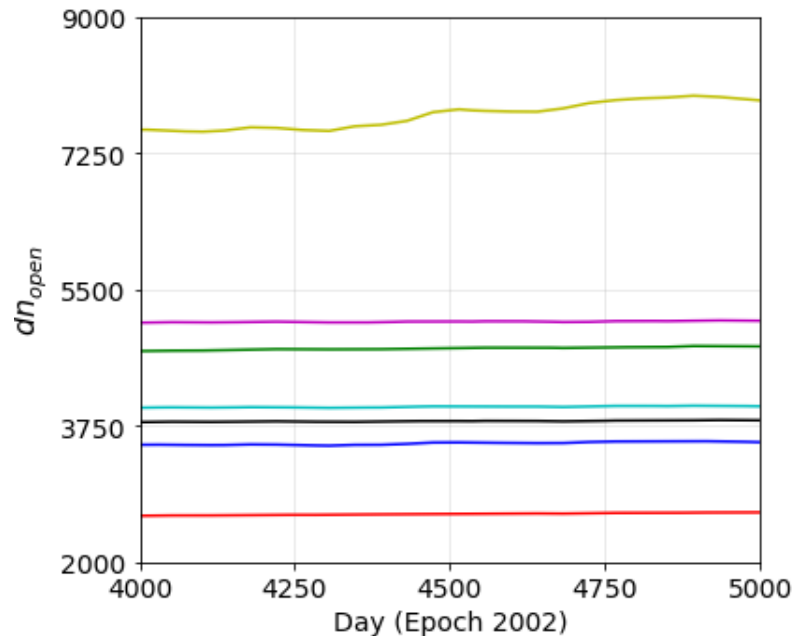
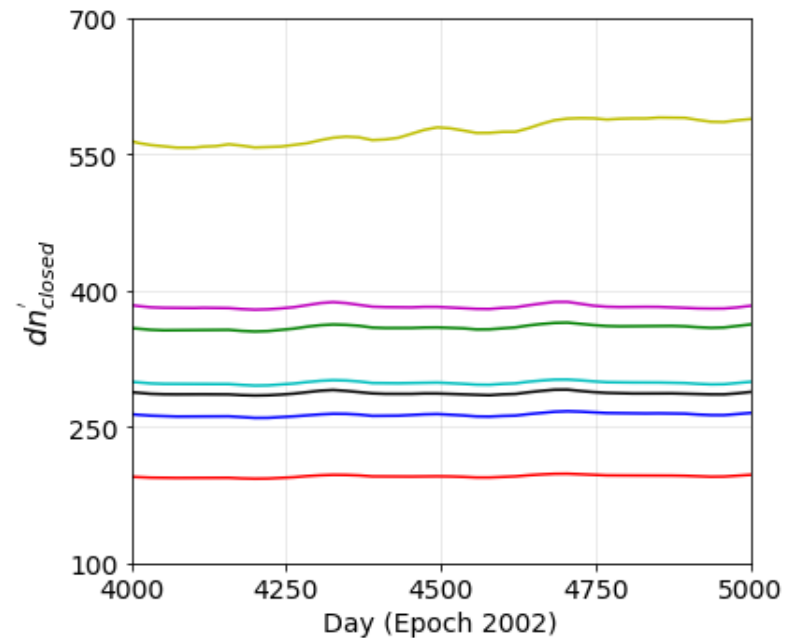
Strategies for SD Calibration

- Extended range of $BRF \cdot VF$ to larger solar angles could be mapped out with more yaw maneuvers (*still TBD*).
 - Expected to work better for Aqua with its SD screen capable of being open and close
- We could use year-to-year overlap to build out $BRF \cdot VF$ as we go, with some added uncertainty.
 - VF is larger concern; BRF has less variation with solar angles.
 - Should work for Terra, but Aqua has less year-to-year overlap (after 2024).



Strategies for SD Calibration

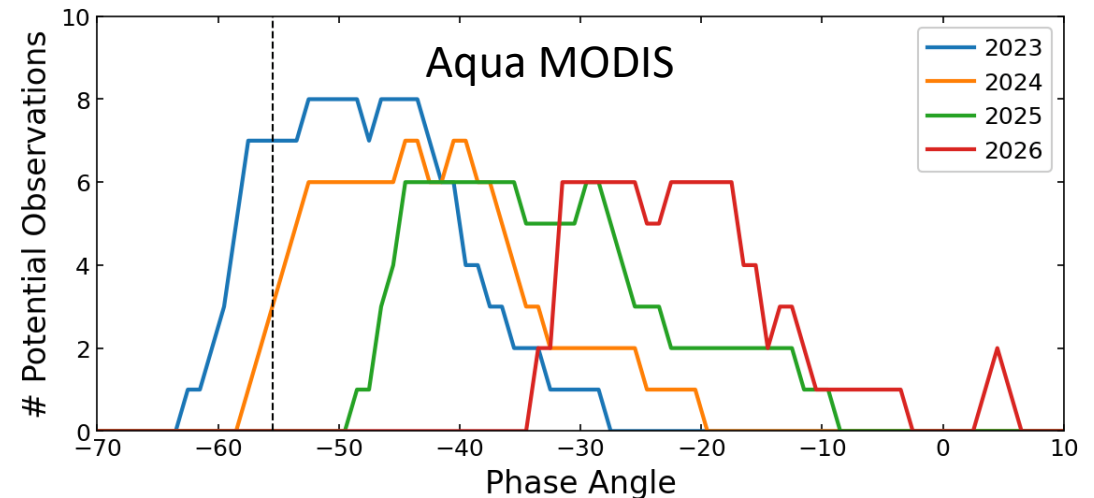
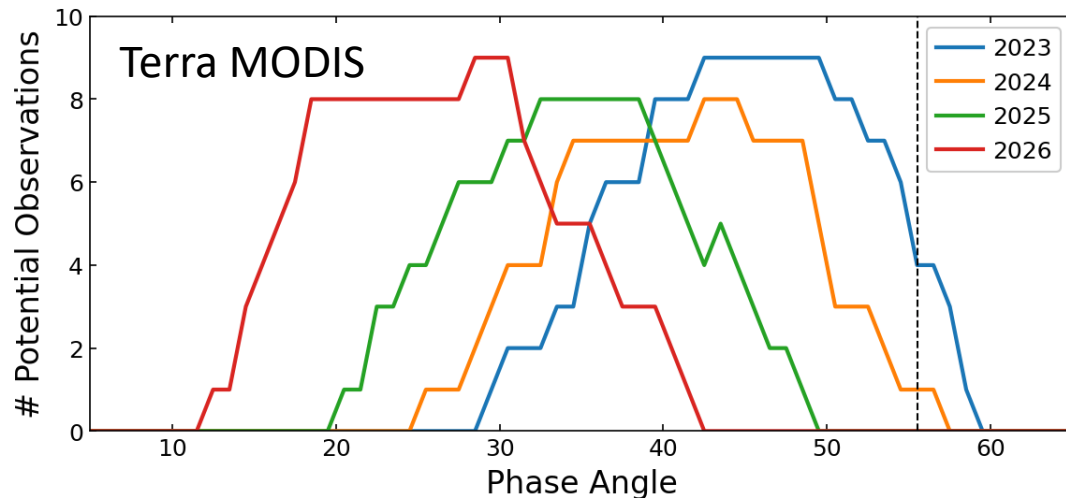
- For Aqua, VF can be characterized for each SD calibration pair (screen open + screen closed) directly.
 - Calculate ratio of dn'_{closed}/dn'_{open} for bands with unsaturated data: bands 1, 2, 3, 4, 18, 19. Apply average ratio as the VF for ocean bands 8-16.
 - Direct on-orbit VF has comparable trends to yaw-derived VF and can be used when solar angles exceed limits of yaw-derived VF.



Strategies for Lunar Observations

- Include a few lunar observations each year at the phase angle (PA) range to be applied in the coming year. The added observations will help determine how much of a residual phase correction (*post-ROLO normalization*) is needed between two different PA ranges.
- Limited use of unscheduled lunar observations

Year	Terra	Aqua
2023	[49, 50]	[-51, -50]
2024	[44, 45]	[-45, -44]
2025	[38, 39]	[-45, -44]
2026	[30, 31]	[-32, -31]

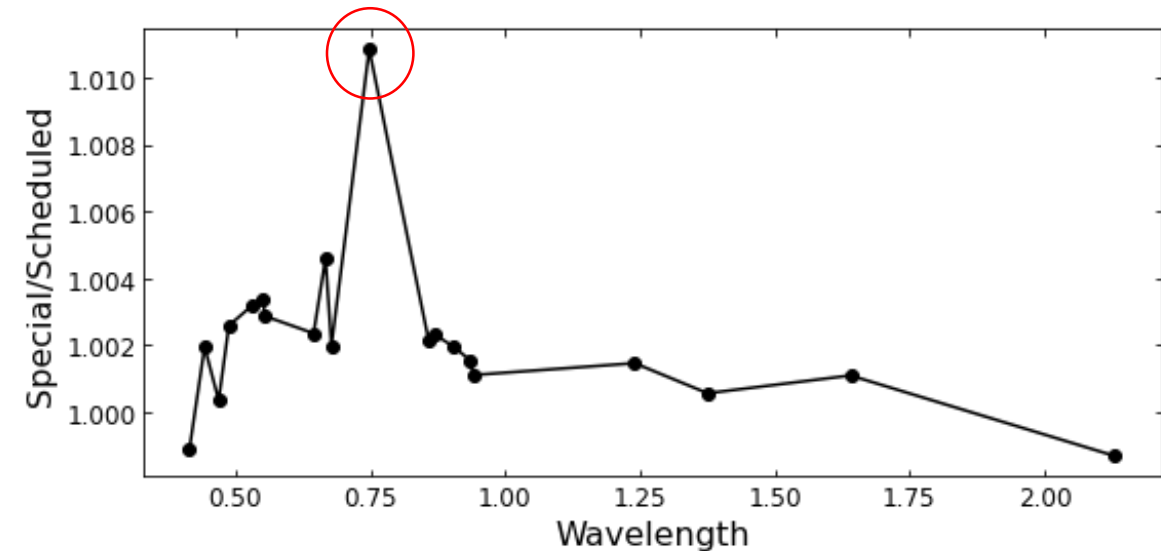


* these PA ranges are subject to change as more accurate ephemeris data is acquired closer to those times

Strategies for Lunar Observations

- Aqua MODIS case:
 - A pair of lunar observations were collected to measure the difference between the nominal phase, -55° , and a new target phase -50° , in December 2022, which will encapsulate the expected phase range for the following year.
 - For most bands, the expected change is small, $\sim 0.2\%$, with the largest changes for the ocean color bands, which partially saturate when viewing the Moon.

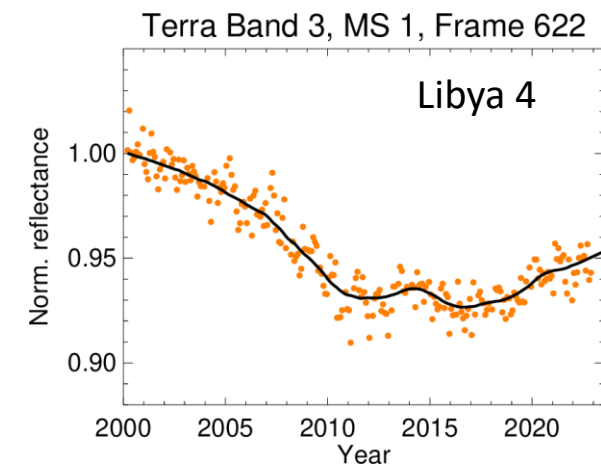
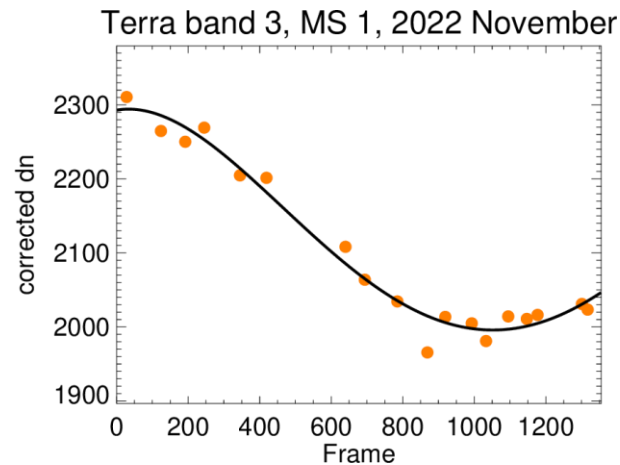
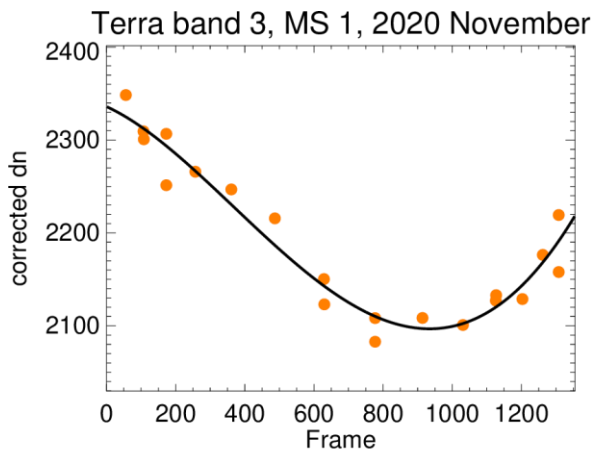
Band 15 (ocean band) with saturated pixels
(UC due to use of ratioing approach)



A similar measurement for Terra MODIS will be performed in January 2023

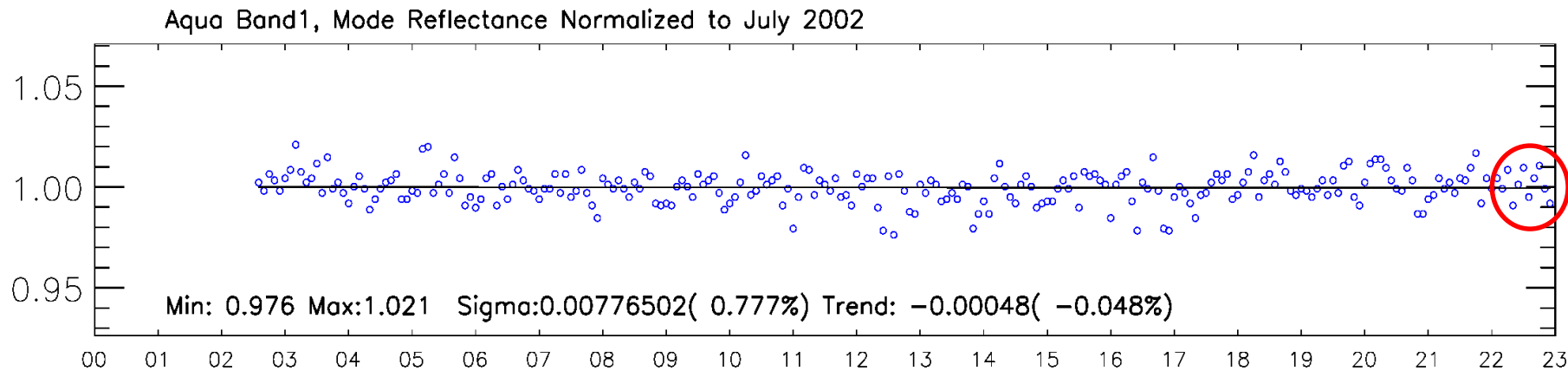
Strategies for Use of Ground Targets

- MCST is shifting to a strategy that aggregates all observations for a single desert site within 1-month intervals to fit the view-angle dependence of signal first, then trend over time.
 - This allows the use of all select desert observations going forward regardless of observation frame.
- An interpolation of the current semi-empirical BRDF is used to extend the BRDF correction to any arbitrary frame (*to be validated*).



Strategies for Use of Ground Targets

- Use of Deep Convective Clouds (DCC)
 - Aggregation of data over lat: [30S, 30N], lon: [95E, 175E]; not sensitive to changes in orbit.
 - DCC reflectance data already tracked at multiple AOI and used to apply RVS corrections for calibration of Terra SWIR bands 5, 6, 7, and 26.
 - Could also be used to aid future calibration for bands 1, 3, 4, and 18 of both MODIS (other bands are saturated).

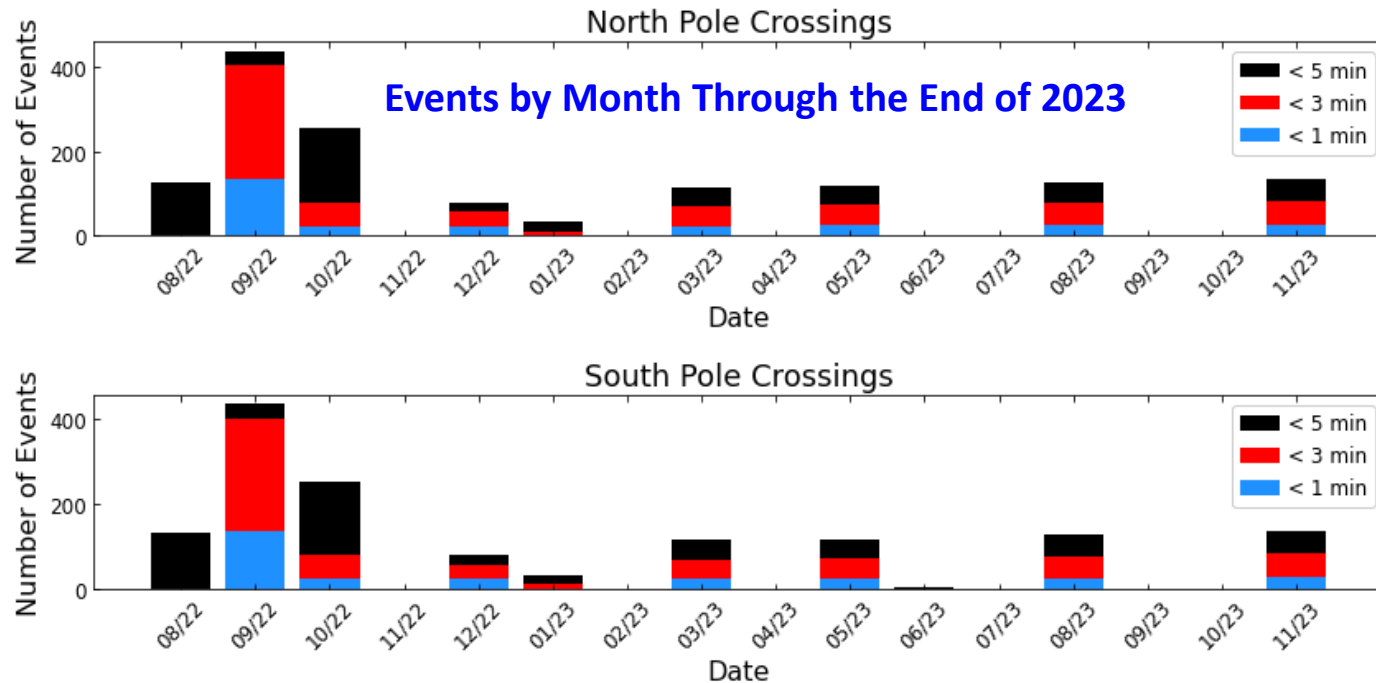


Last 10 months of Aqua ground track drift had no impact on number or accuracy of DCC observations.

- Dome C
 - Little impact on the use of Dome-C site because it is observed for many orbits in a day unlike the desert sites which is twice per day (one day and one night)

Direct Calibration Inter-comparison of T/A MODIS

- Previous approaches for MODIS calibration inter-comparison include use of double difference with a third sensor (LEO or GEO) or RTM simulation
- Drifting orbits generate opportunities for direct calibration inter-comparison of Terra and Aqua MODIS via near simultaneous nadir overpasses (SNO)
- Effort is underway for a more comprehensive and direct assessment of T/A MODIS calibration difference (RSB and TEB)



This data is generated using TLE archives up through the end of December 2022. After that, only the last available TLE was used.

The SNO events have a frequency of around 2-3 months in the upcoming year.

Summary

- For more than two decades, extensive efforts have been made by members of MCST for Terra and Aqua MODIS on-orbit calibration
- Recent effort includes developing and implementing new calibration strategies and approaches to address the impact due to Terra and Aqua's drifting orbits
 - Primary impact on RSB calibration
 - Less impact on TEB calibration
- Continue working closely with Terra and Aqua flight operation teams (FOT) - expect the unexpected and make timely adjustments if the situation presents itself