



# International Earth Science Constellation Mission Operations Working Group (MOWG)

December 3-5, 2019

## Constellation Exit Analysis

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## Contents

- Introduction
- Assumptions
- Under Flight Analysis
- Burn Separation Analysis
- Burn Location Analysis
- Conclusions

## Introduction

- The spacecraft teams are preparing for eventual exit from the constellation.
- Independent analyses have been performed for the Aqua and Terra missions.
- This presentation will present results for several key areas including under flight (UF) and burn location impact on frozen orbit.

## Assumptions

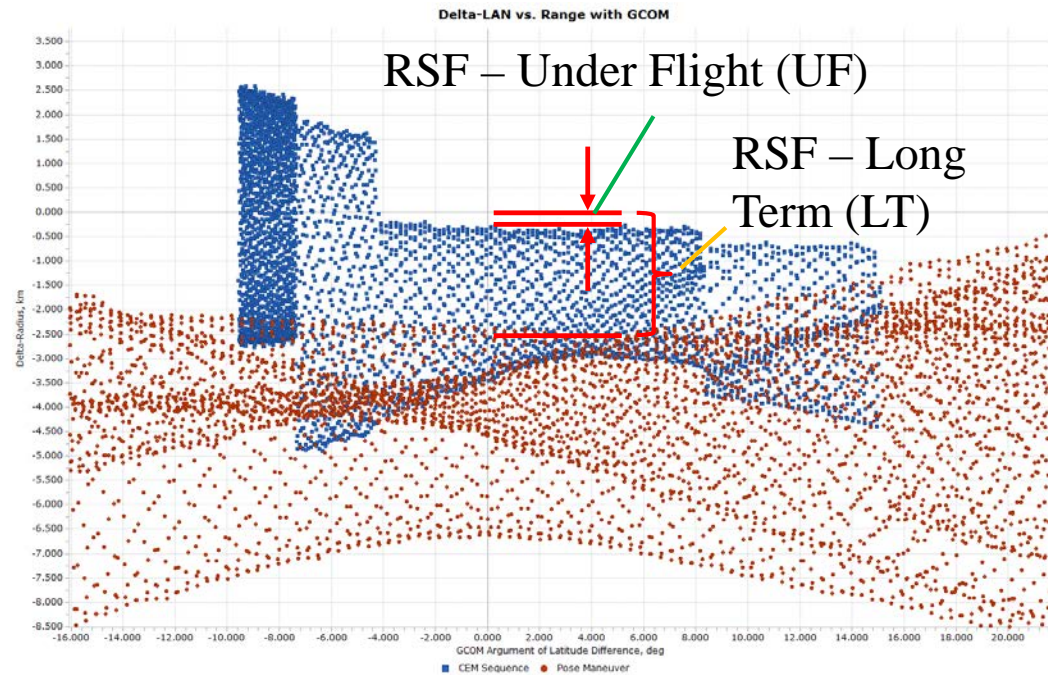
- Maximum burn duration is 560 seconds for Aqua and 320 seconds for Terra.
- Remaining fuel for the spacecraft is based on lifetime analysis.
- Aqua TSF based on IAM trending values, Terra TSF used a constant 0.97.
- Assumed spacecraft centered on frozen orbit at the start of the Constellation Exit Maneuver (CEM) burns.
- Assumed burn pairs achieve similar delta-v magnitudes.

## Under Flight Analysis

- Purpose: to assess the risk of a conjunction between constellation exit maneuver burns with members of the constellation and develop a plan that minimizes this risk.
- This analysis uses Aqua and GCOM W-1 since their potential interaction is likely, given their orbit geometry and relative phasing

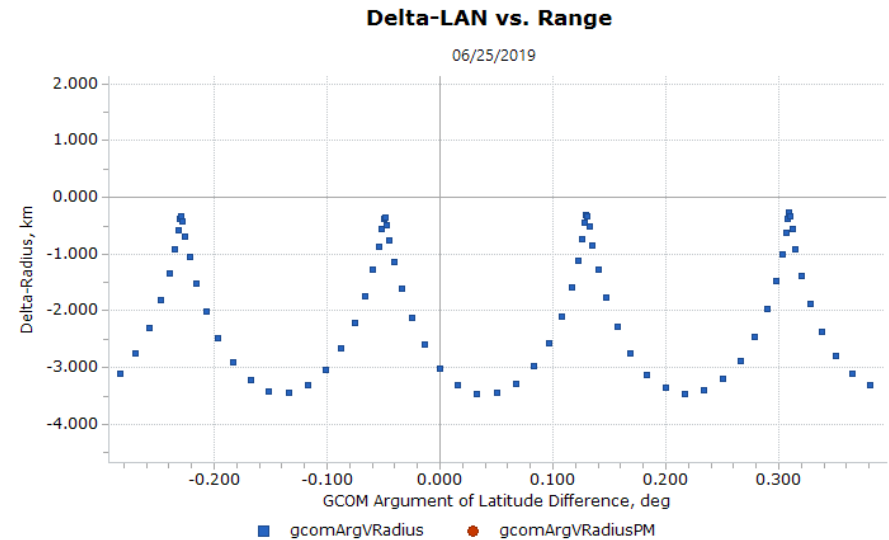
## Radius Safety Factor RSF

- Difference in Radius ( $\Delta R$ ) at difference in Argument of Latitude ( $\Delta L$ ) = 0 is the minimum radius difference of a close approach, called the Radius Safety Factor (RSF) as a metric of safety for the under flight.
  - For this example, the minimum  $\Delta R$  is less than 0.25 km during the CEM sequence (blue), but is approximately 2 km long term (red).



## Under Flight – Consider Short Periodics

- Short periodic variation during the CEM shows that, for this case, the actual radius separation at  $\Delta L = 0$  is 3 km
- However, due to relative orbit geometry, the actual TCA of any under flight may not occur exactly at  $\Delta L = 0$ , but can vary by several tenths of a degree
- Therefore, the actual radius difference can take on any value between the maximum and minimum of the short periodic

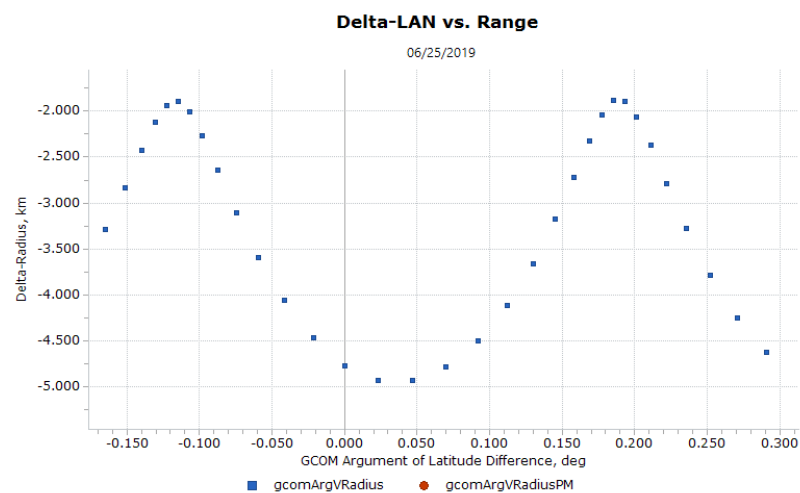
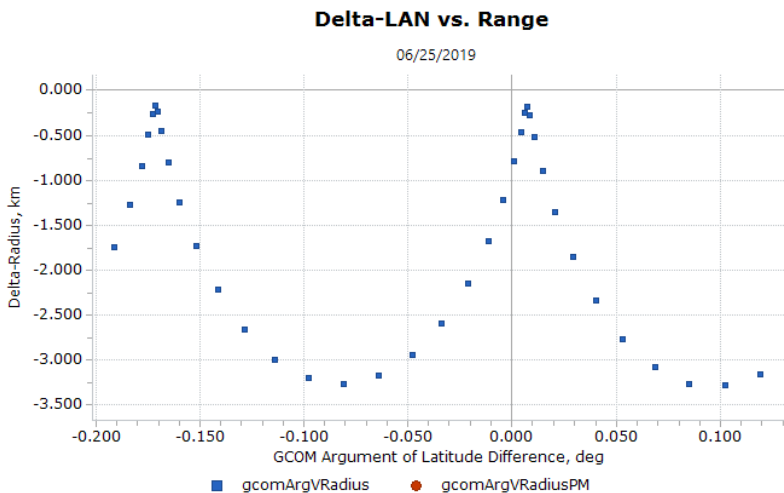


## Controlling Min and Max Radius Separation

- The minimum and maximum radius differences are driven primarily by the magnitude of the first two maneuvers
  - Burn location has a secondary impact

Burn durations ~ 320 seconds

Burn durations ~ 560 seconds

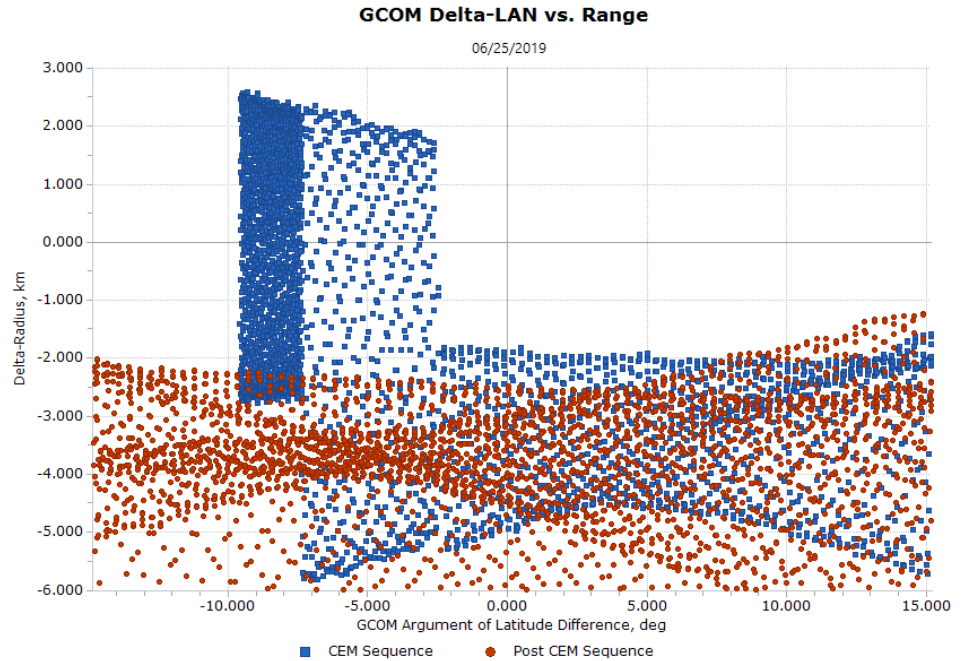


## Aqua Maneuver Plan

- 4 maneuvers; 2 Maximum burn duration; 2 “trim” burns

#	Day	DT (sec)	L (deg)
1	1	560	0 (day)
2	3	560	180 (night)
3	8	89	0 (day)
4	10	89	180 (day)

Results	
UF Miss, km	10
RSF – UF, km	1.8
RSF – LT, km	2.5



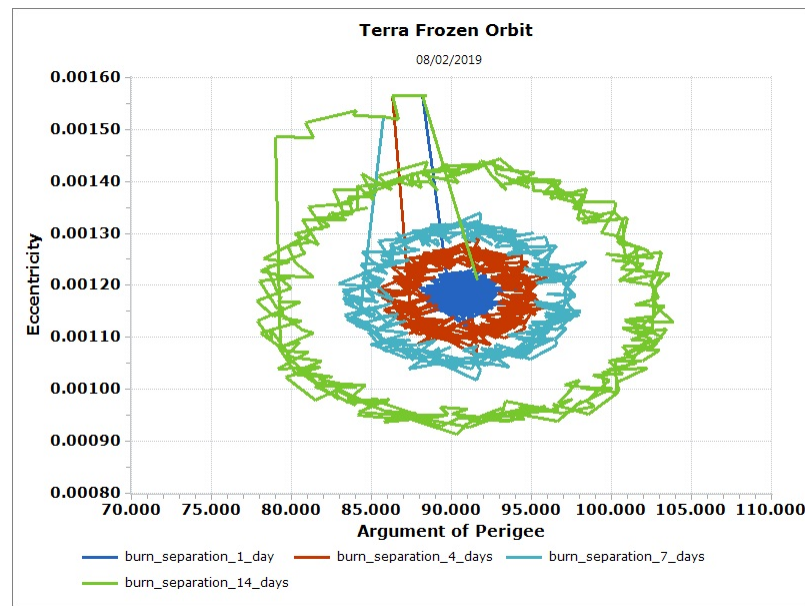
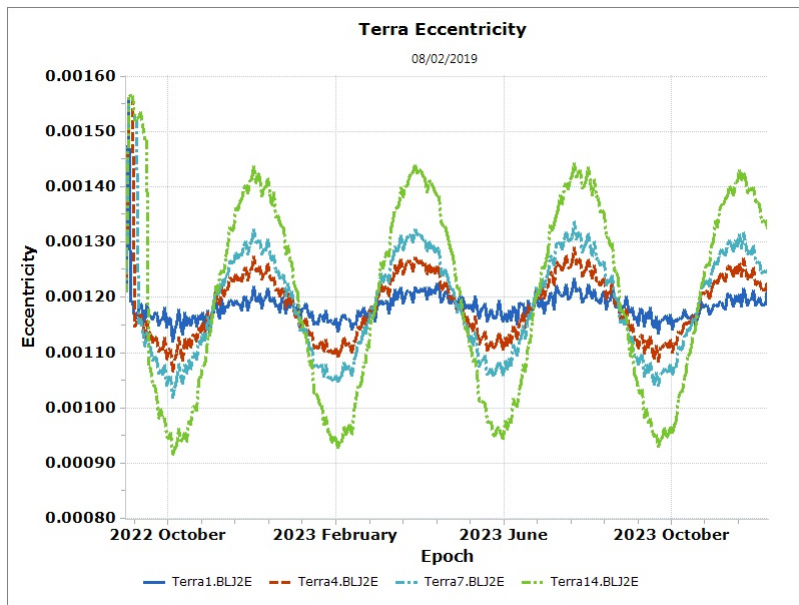
- Miss distance and CEM RSF maximized by maximum delta-SMA prior to under flight

## **Burn Separation Analysis**

- Purpose: To analyze the effects that the time between burns has on Terra's frozen orbit.

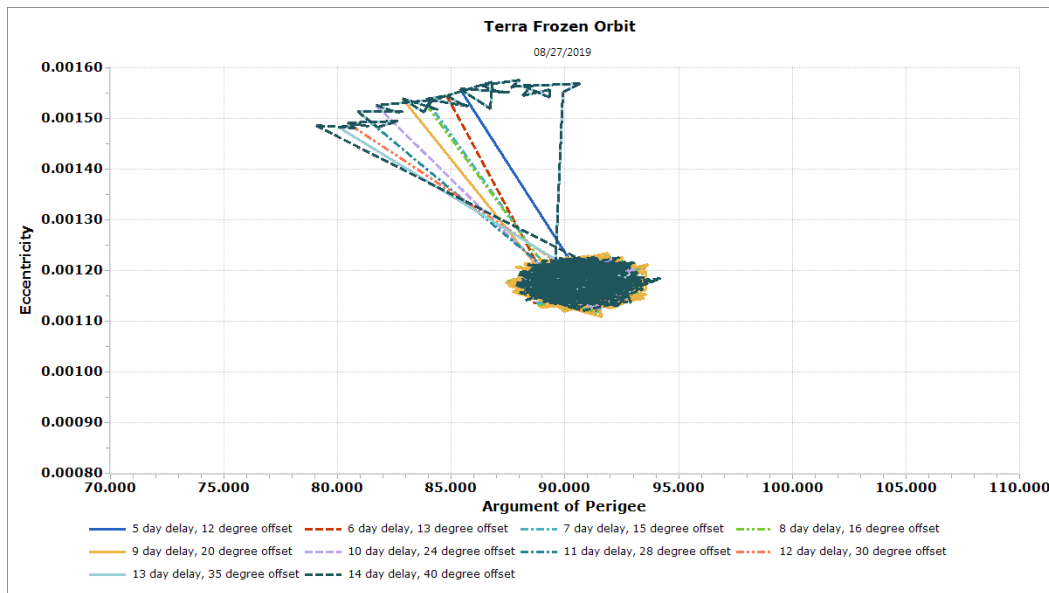
## Burn Separation Effects on Frozen Orbit

- Burn separations of 1, 4, 7, and 14 days frozen orbit and eccentricity plotted together.
- The longer the separation between burns, the more Terra's frozen orbit is impacted, however, the bounds of the frozen orbit will not be violated by burn separations less than 21 days.



## Re-Centering the Frozen Orbit

- If significant time (greater than 5 days) was spent between each burn, the second burn could be purposely phased to re-center Terra's frozen orbit. Should any unexpected delays occur, this can be used to restore the frozen orbit.
- The graph shows burns separated by 5 through 14 days with the second burn offset to restore the tight frozen orbit.



## Re-Centering the Frozen Orbit

- The table shows how the second burn should be phased with the first in order to re-center the frozen orbit.
- By phasing the burn by 140 degrees, the final apogee and perigee could be 500 m off from a nominal 180 degree phasing.
- This will, however, reduce the efficiency of lowering the orbit.

Burn Separation (days)	Burn Phasing (degrees)
5	168
6	166
7	165
8	164
9	160
10	156
11	152
12	150
13	145
14	140

## Burn Location Analysis

- Purpose: To analyze the effects of changing the location of the first burn from apogee and the effects of different phasing of the second burn.

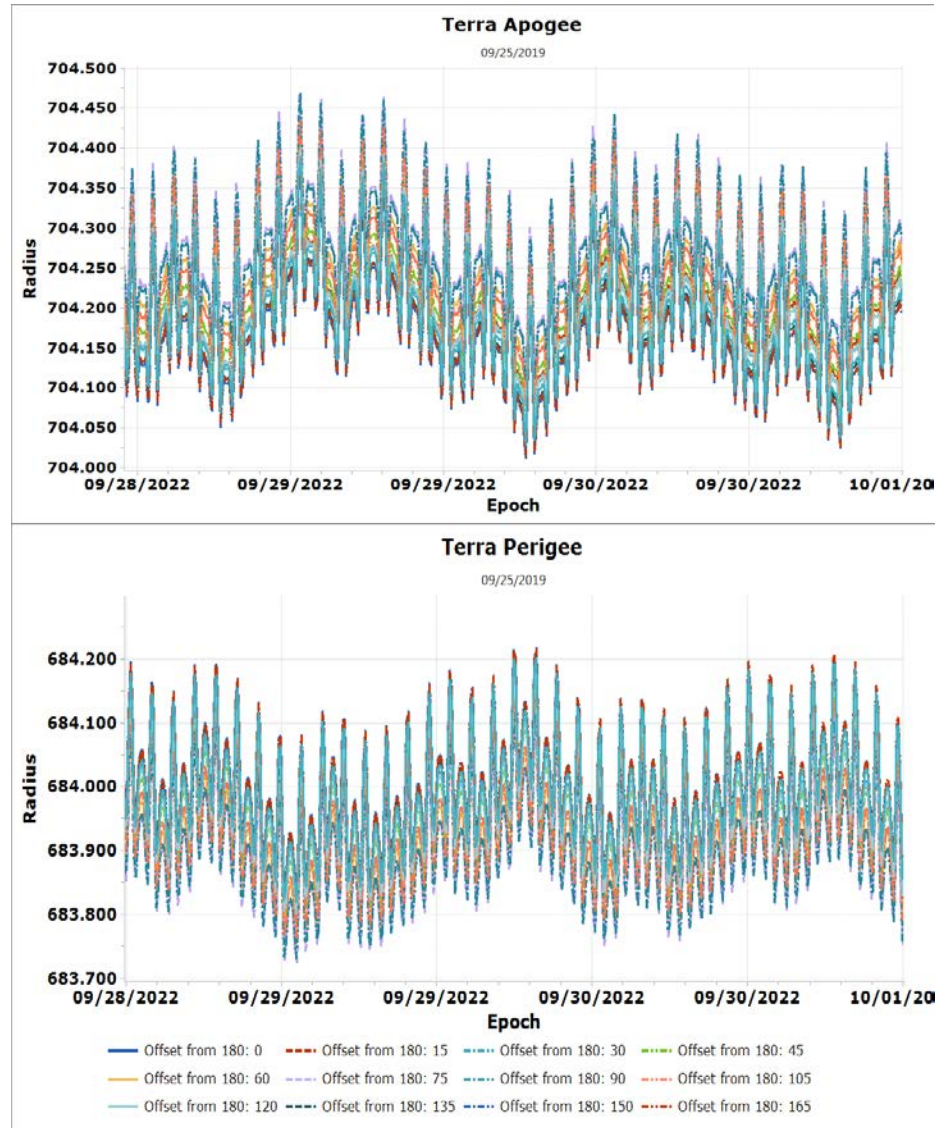
## Shifting First Burn Location

- This video shows how the frozen orbit is effected by shifting the first burn.
  - Burn pairs 180 degrees apart.
- The bounds of the graph are Terra's frozen orbit limits.
  - Eccentricity:  $0.0012 \pm 0.0004$ .
  - Argument of Perigee:  $90 \pm 20$  deg.
- Because Terra's orbit is nearly circular, centering the burn at a location other than apogee does not have a major effect on the final orbit so long as the second burn is still phased at 180.

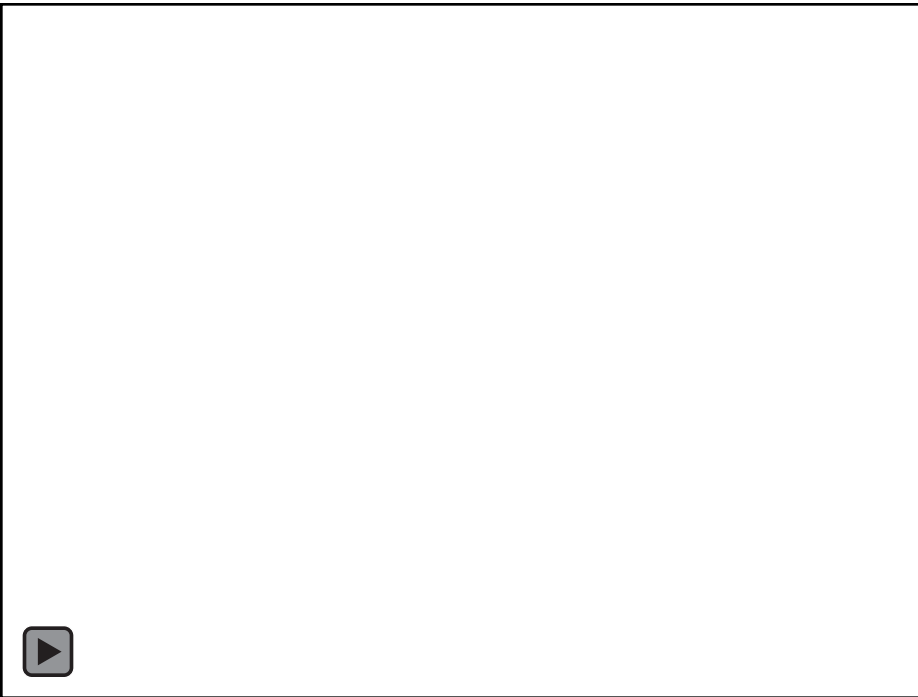


## Shifting First Burn Location

- Shifting the apogee has little effect on the final apogee and perigee.
- There is a 100 m difference between the highest and lowest resulting apogee.
- There is also a 100 m difference between the highest and lowest resulting perigee.



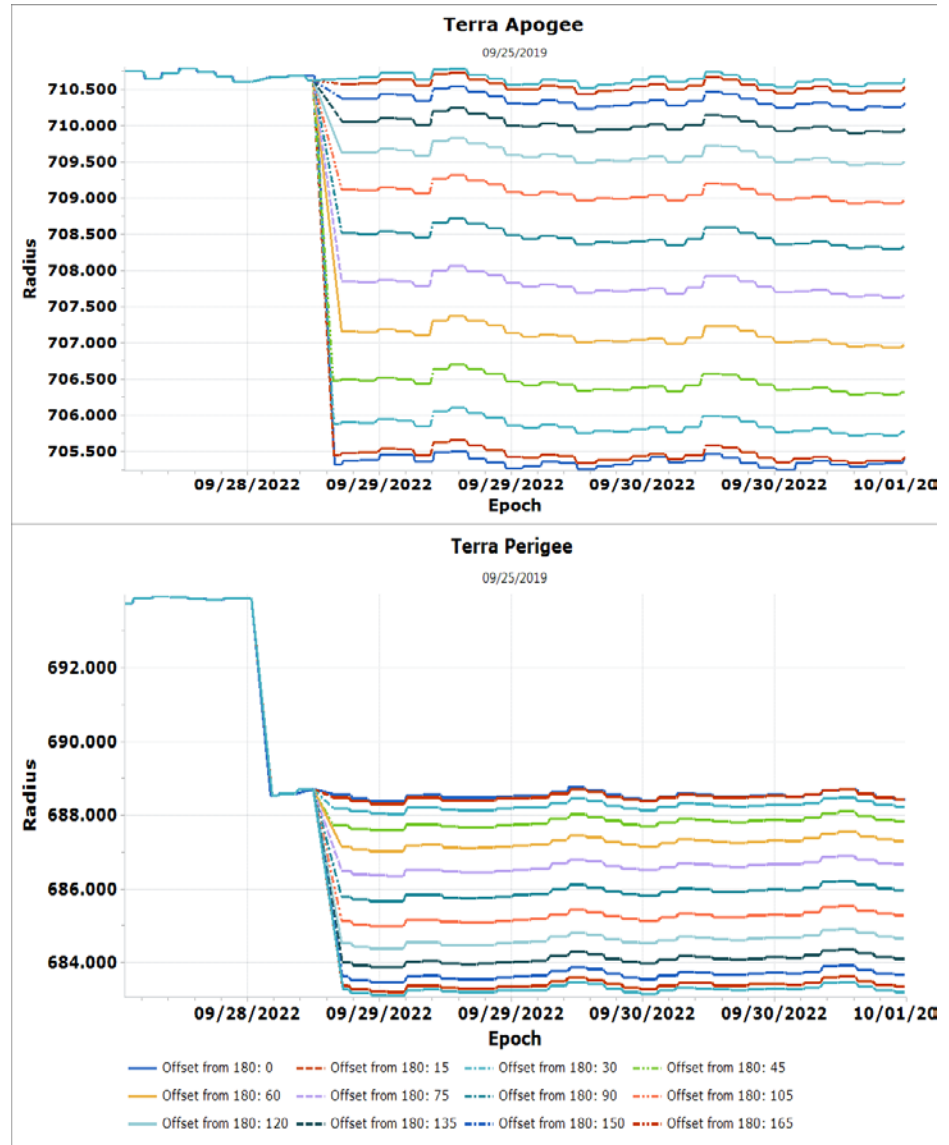
## Shifting Second Burn Location



- This video shows how the frozen orbit is effected by phasing (i.e. relative location) of the second burn.
  - The first burn was fixed while the second was varied.
- The bounds of the graph are Terra's frozen orbit limits.
- For phasing less than about 90 degrees and greater than about 270 degrees, the frozen orbit limits will be violated.
- By shifting the phasing, you can shift the center of Terra's frozen orbit.

## Shifting Second Burn Location

- Phasing the second burn has a significant impact on the final apogee and perigee.
  - With no phasing between burns, there is no change in the final apogee, and the change in perigee doubles from the nominal case.
  - An offset of 15 degrees from the nominal 180 degree phasing will change the orbit by about 200 m.



## Conclusions

- The best CEM plan to reduce the risk of a close under flight is to perform the first burn pair with the longest possible duration, then perform trim burn pairs as needed.
- While the time between CEM burns does have a significant effect on a spacecraft's frozen orbit, it is not enough to violate the frozen orbit within a reasonable span of time.
  - The current plan is to perform Terra's CEM burn pair with a day of separation
- Shifting the first burn from apogee does not effect frozen orbit or final apogee and perigee so long as the second burn is phased by 180 degrees with the first.