Orbit Determination For The James Webb Space Telescope During Launch And Early Orbit

AAS 22-607

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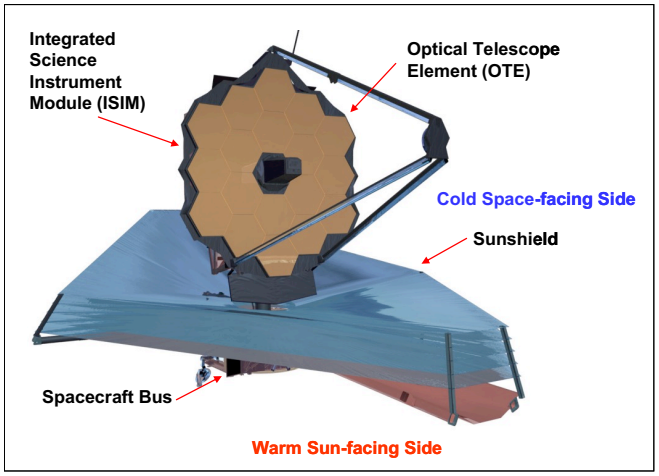
Outline

- Introduction
- Orbit Determination (OD) For 1st Mid-Course Correction Maneuver (MCC-1a)
- OD For MCC-1b
- OD For MCC-2
- OD For 1st Station Keeping Maneuver (SK-1)
- Conclusion

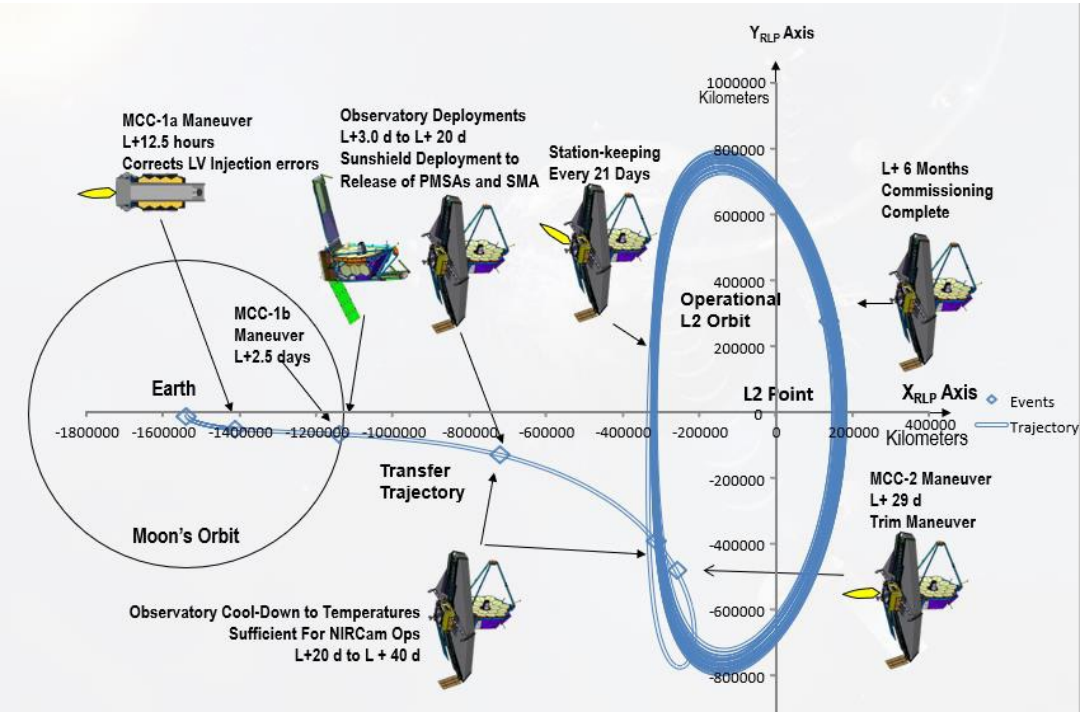
Introduction

- JWST launched on December 25, 2021, at 12:20 UTC
- Sunshield and mirror segments required multi-stage deployment process
- Spacecraft inserted into operational orbit about L2 in the Sun-Earth-Moon system on January 24, 2022, at 19:00 UTC



Introduction

- Due to thermal constraints, JWST cannot thrust in the anti-Sunward direction
- Launch injection state biased down to avoid overshooting L2
- Performed 3 maneuvers to get to L2
  1. MCC-1a
  2. MCC-1b
  3. MCC-2



Introduction

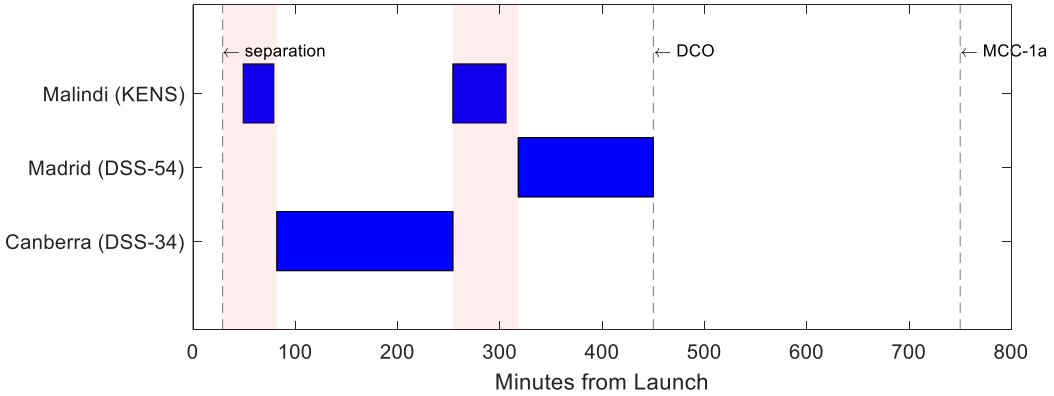
- Continuous range and Doppler tracking provided by Deep Space Network (DSN) and the Malindi ground station in Kenya
- 2 different OD estimators/techniques
  - Extended Kalman Filter (EKF) - Orbit Determination Tool Kit (ODTK)
  - Batch Least Squares (BLS) - Goddard Trajectory Determination System (GTDS)
- BLS was used in early part of mission due to short tracking arcs, switched to EKF after MCC-1b

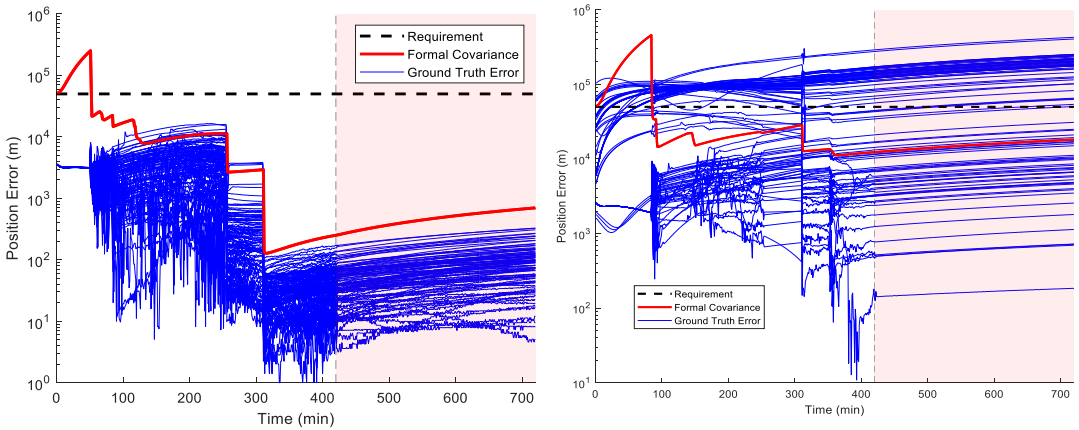
Mission Phase	Nominal Start Time	Nominal Stop Time	Primary Estimator
LV sep. to MCC-1a	Dec. 25, 2021, 12:47 UTC	Dec. 26, 2021, 00:50 UTC	BLS
MCC-1a to MCC-1b	Dec. 26, 2021, 00:50 UTC	Dec. 28, 2021, 00:20 UTC	BLS
MCC-1b to MCC-2	Dec. 28, 2021, 00:20 UTC	Jan. 24, 2022, 19:00 UTC	EKF
MCC-2 to first SK	Jan. 24, 2022, 19:00 UTC	Feb. 16, 2022, 21:55 UTC	EKF

Maneuver	3-σ RSS Position Requirement	3-σ RSS Velocity Requirement
MCC-1a	50 km	30 cm/s
MCC-1b	50 km	10 cm/s
MCC-2 and SK	50 km	2 cm/s

OD For MCC-1a

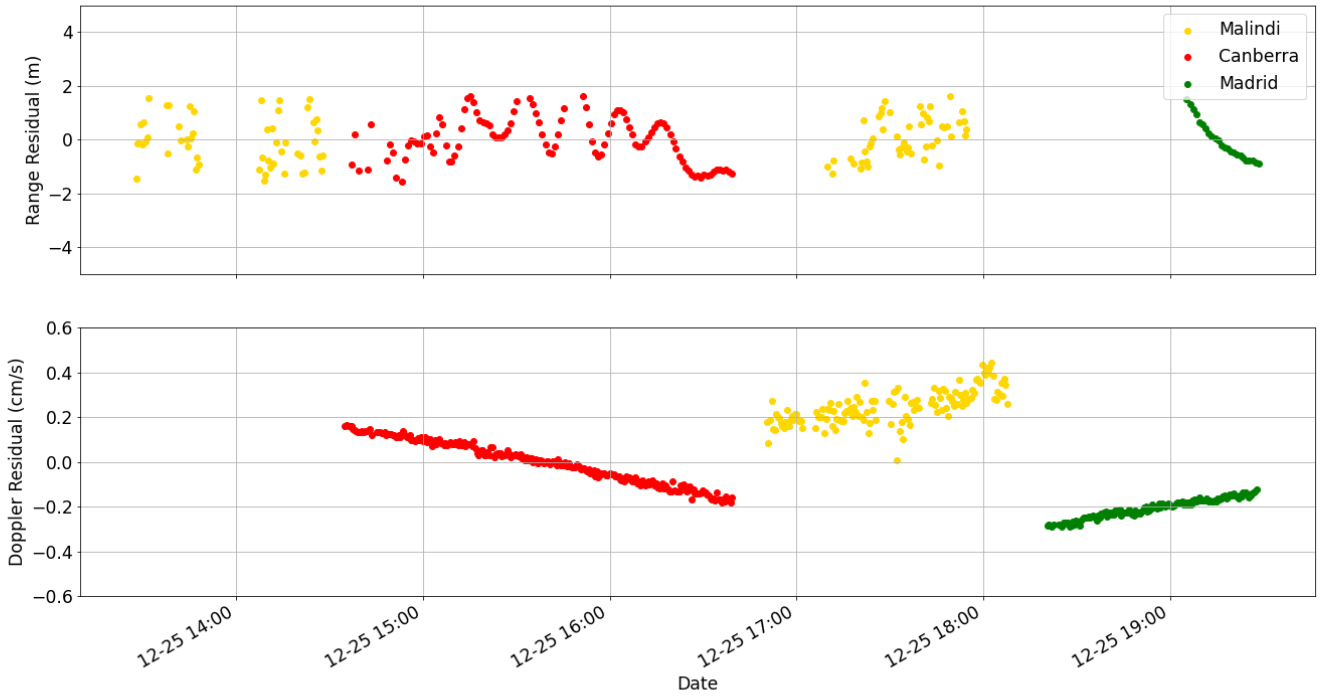
- MCC-1a occurred 12.5 hours after launch (L+12.5 hours) on December 26, 2021, at 00:50 UTC
- OD solution used to plan MCC-1a delivered at L+7 hours, only 6.5 hours of tracking data used
- Pre-launch analysis showed Malindi tracking was necessary to meet OD requirements prior to MCC-1a





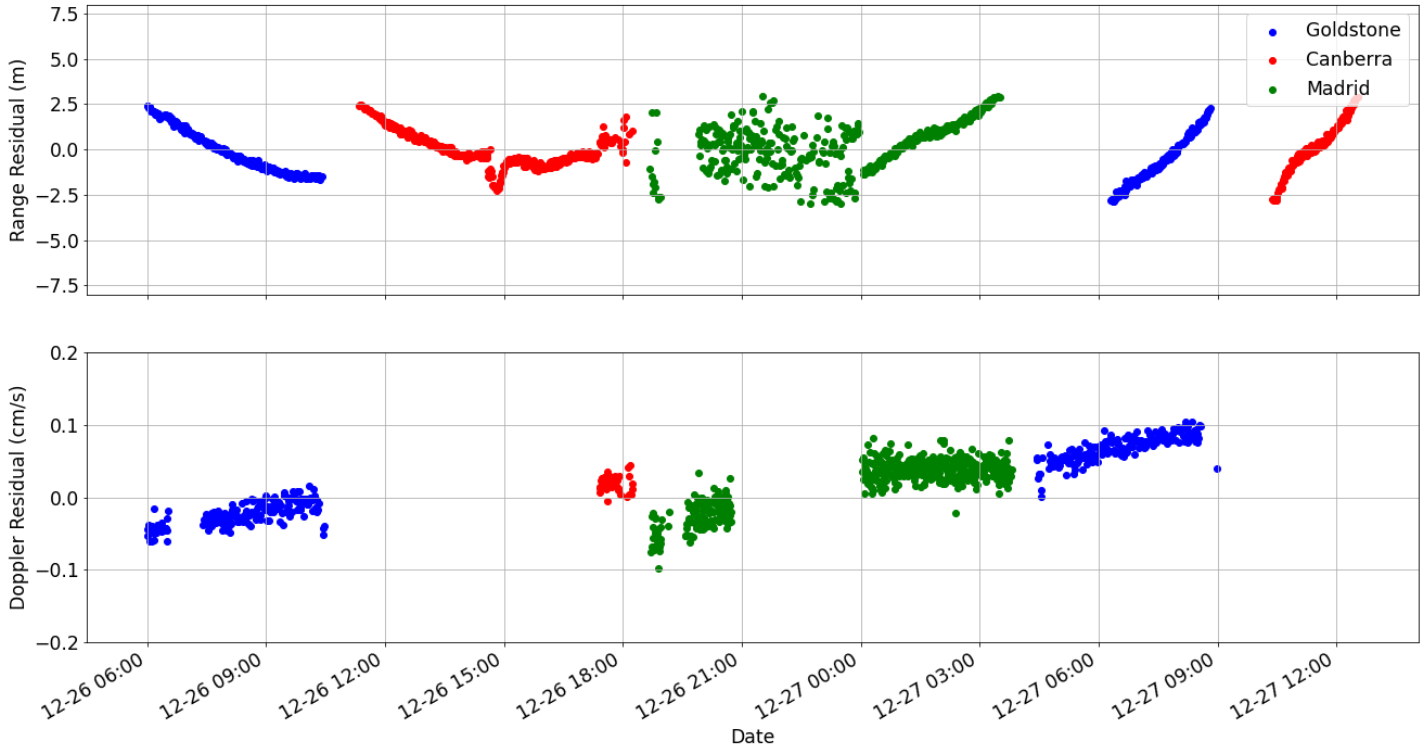
OD For MCC-1a

- Noise on residuals was small – however, residuals showed some structure likely due to attitude modeling errors
- 1545-meter bias was observed and corrected for in the Malindi range data, first Malindi Doppler pass was very noisy and was not included



OD For MCC-1b

- MCC-1b was executed on Dec. 28, 2021, 00:20 UTC
- Pre-launch OD analysis showed errors an order of magnitude below requirements
- BLS and EKF solutions both converged, with BLS as primary estimator
  - Resulting trajectories from BLS/EKF agree to within ~1 km

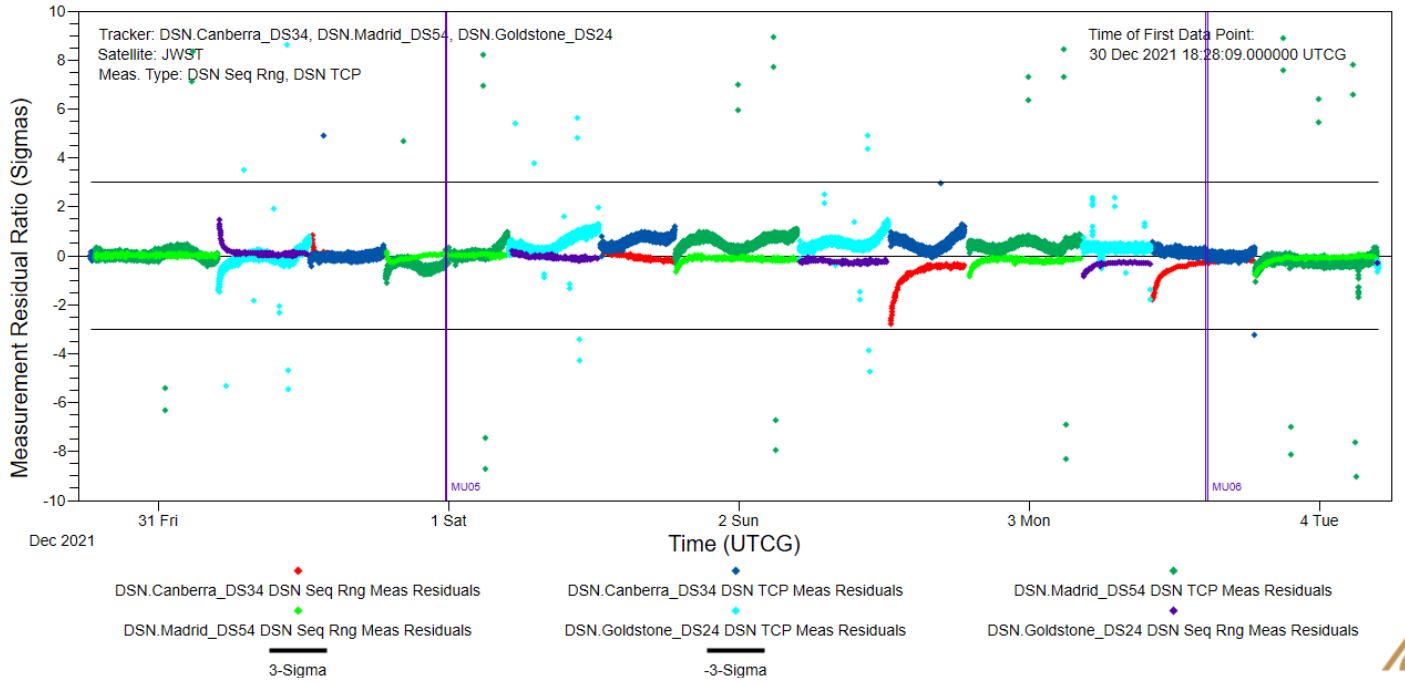


OD For MCC-2

- MCC-2 executed on Jan. 24, 2022, 19:00 UTC, OD arc spanned 4 weeks
- Sunshield deployments occurred during this phase, which changed the SRP area
- Transition from BLS to EKF took place over first week of phase after MCC-1b

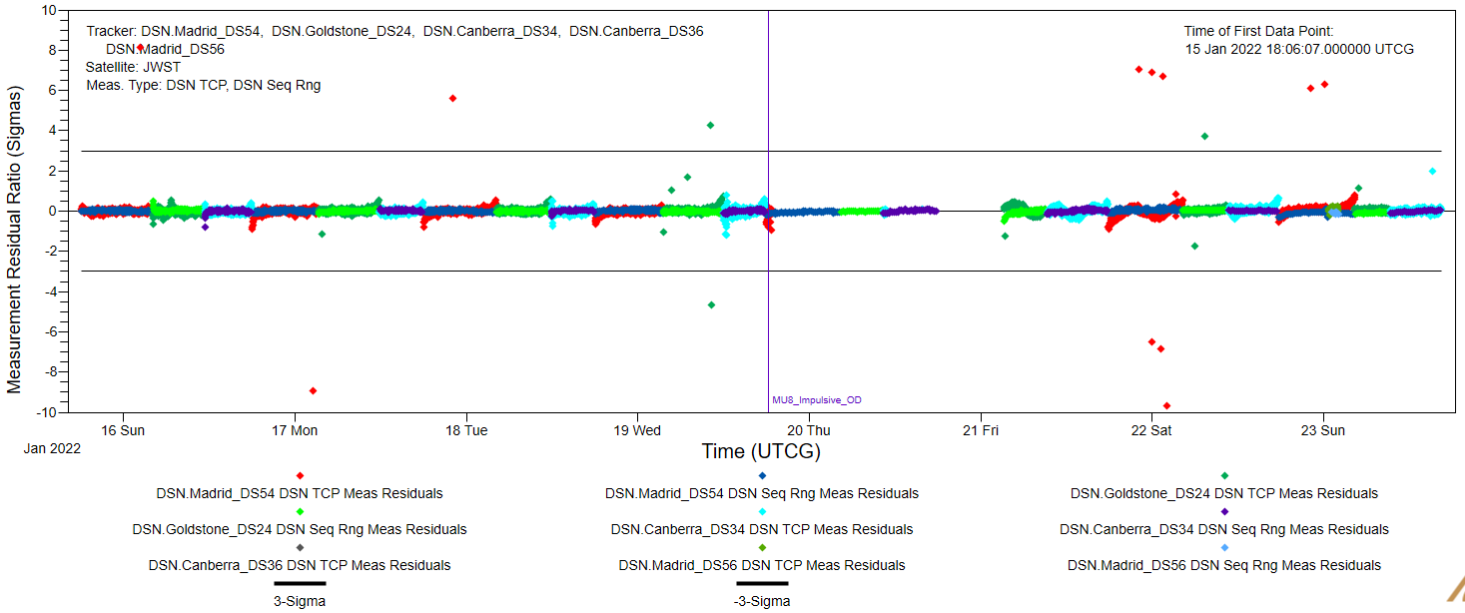
OD For MCC-2

- Major sunshield deployments, incomplete attitude telemetry, and frequent momentum unloads made OD challenging, introduced signatures in measurement residuals



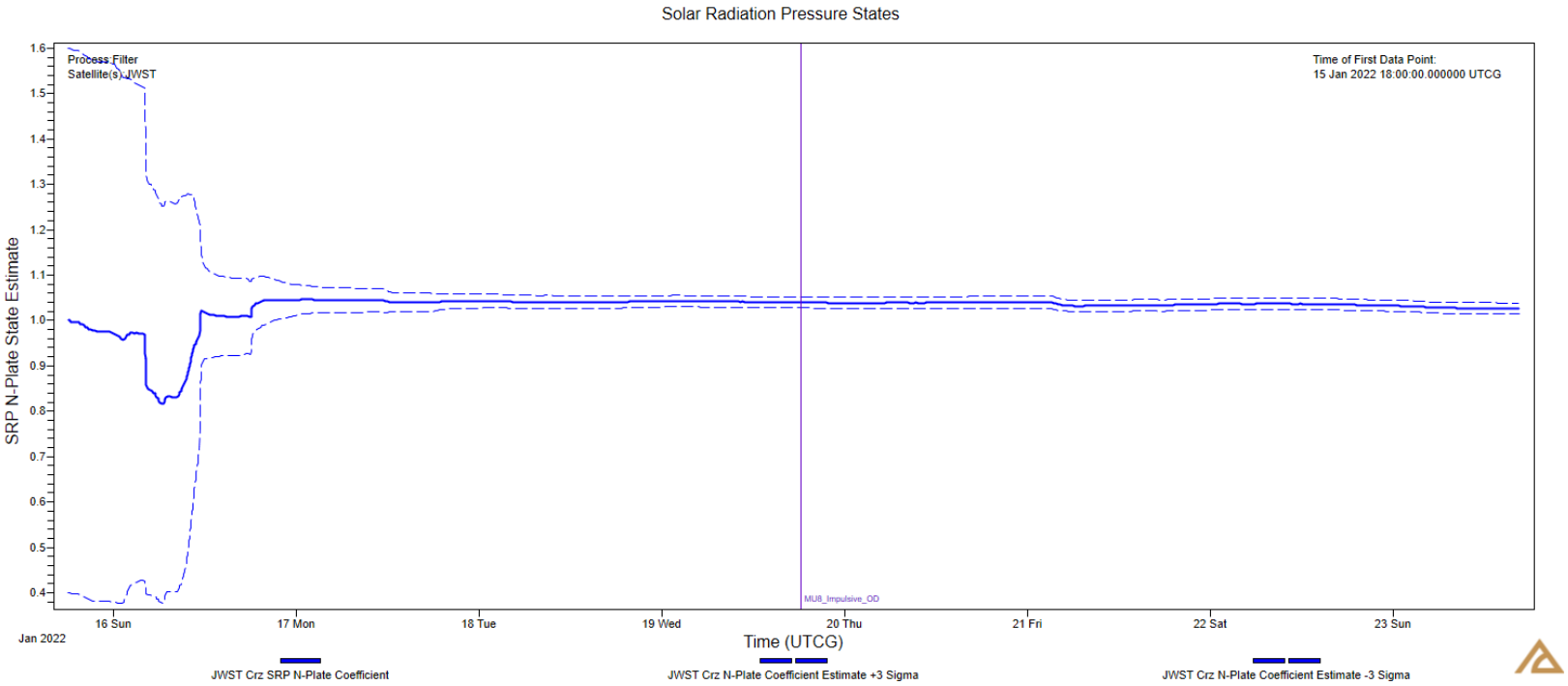
OD For MCC-2

- Started receiving full attitude telemetry after deployments, much less structure in residuals



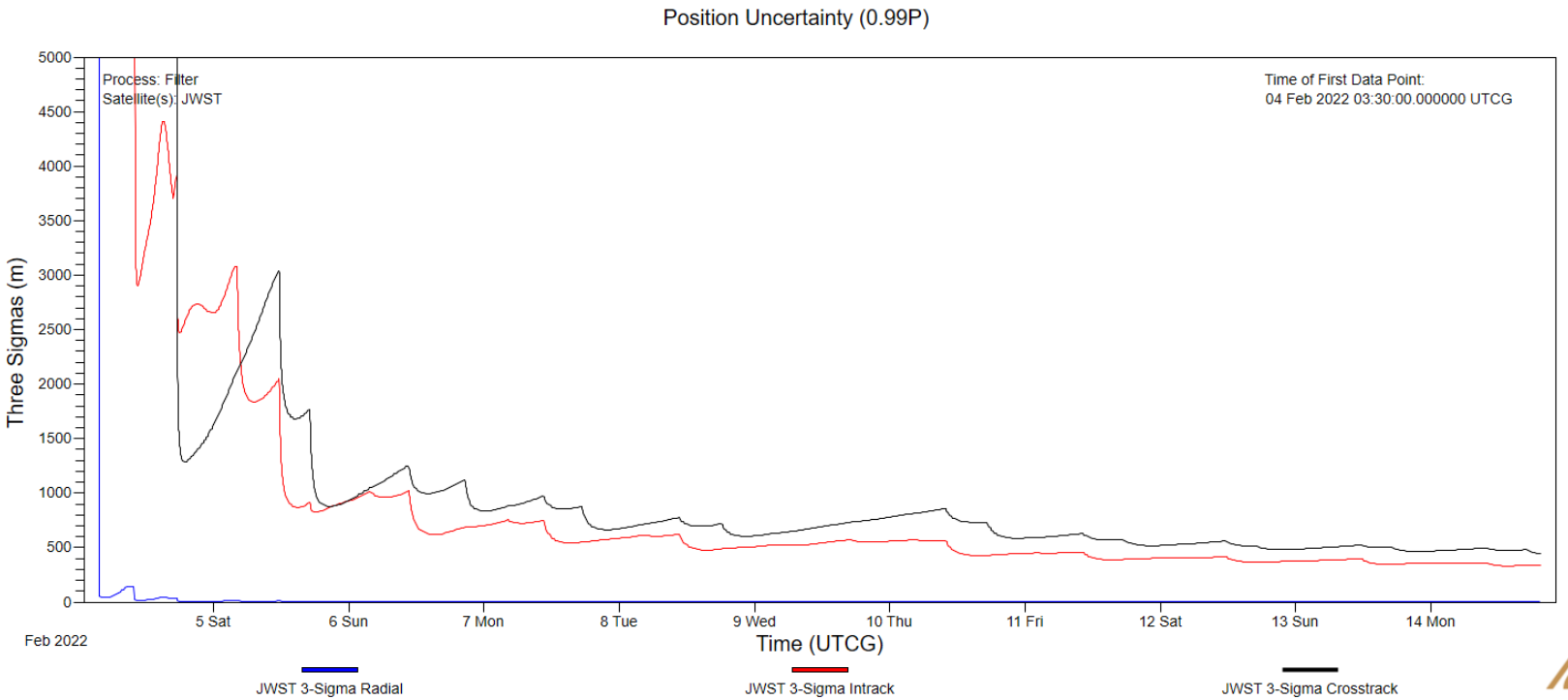
OD For MCC-2

- SRP force modeled using polynomial curve-fit to ray-traced model
- Started estimating Z-component of SRP coefficient after deployments, estimated value was ~4% higher than nominal model



OD For SK-1

- SK maneuvers are performed every 21 days to maintain Lissajous orbit
- 1st SK maneuver was executed on February 16, 2021, at 21:55 UTC
- Filter was well-tuned by 1st SK, received full attitude information



Conclusion

- First OD arc used to plan MCC-1a was extremely short, but through pre-launch analysis the team was prepared for contingencies, and gained confidence in the final OD solution

- OD team successfully switched from the BLS to EKF and ran solutions throughout the sunshield deployment and momentum unloads to prepare for MCC-2

- Team developed tuned OD setup to support 1st SK maneuver and future operations in science orbit

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References

1. P. Bernath, C. McElroy, M. Abrams, C. Boone, and M. Butler et al., "Atmospheric chemistry experiment (ACE): mission overview," *Geophysical Research Letters 32.15* (2005).
2. V. Domingo, B. Fleck, and A. Poland, "The SOHO mission: an overview," *Solar Physics* 162.1, 1995.
3. J. Burt and B. Smith, "Deep space climate observatory: The DSCOVR mission," *IEEE aerospace conference*, 2012.
4. C. Bennett, D. Larson, J. Weiland, N. Jarosik, and G. Hinshaw et al., "Nine-year Wilkinson Microwave Anisotropy Probe (WMAP) observations: final maps and results," *The Astrophysical Journal Supplement Series 208.2*, 2013.
5. T. Cesari, "First Look: NASA's James Webb Space Telescope Fully Stowed," NASA, https://www.nasa.gov/feature/goddard/2020/first-look-nasa-s-james-webb-space-telescope-fully-stowed, 2020.
6. K. Richon, J. Peterson, and A. Nicholson, "Flight Dynamics Planning and Operations Support for the JWST Mission," *AAS/AIAA Astrodynamics Specialist Conference*, 2022.
7. J. Peterson, K. Richon, and B. Stringer, "Planning and Execution of the Three Mid-Course Correction Maneuvers for the James Webb Space Telescope," *AAS/AIAA Astrodynamics Specialist Conference*, 2022.
8. W. Yu, T. Rashied, A. Santacroce, B. Stringer, and J. Lorah, "JWST Real-Time Mid-Course Correction Maneuver Monitoring Contingency Preparation," *AAS/AIAA Astrodynamics Specialist Conference*, 2022.
9. W. Yu and K. Richon, "Launch Window Trade Analysis for the James Webb Space Telescope," *International Symposium on Space Flight Dynamics*, 2014.
10. J. Peterson, J. Tichy, G. Wawrzyniak and K. Richon, "James Webb Space Telescope Initial Mid-Course Correction Monte Carlo Implementation using Task Parallelism," *International Symposium on Space Flight Dynamics*, 2014.
11. T. Rashied, B. Stringer, J. Petersen, and K. Richon, "Mid-Course Correction Contingency Analysis for the James Webb Space Telescope," *AAS/AIAA Astrodynamics Specialist Conference,* 2019.
12. S. Yoon, J. Rosales, and Karen Richon, "James Webb Space Telescope Orbit Determination Analysis," *International Symposium on Space Flight Dynamics*, 2014.
13. M. Greenhouse, "The James Webb Space Telescope: Mission overview and status," *2nd International Conference on Space Technology*, 2011.
14. NASA GSFC, https://webb.nasa.gov/content/webbLaunch/deploymentExplorer.html, 2020.
15. A. Farres, J. Petersen, and K. Richon, "Solar Radiation Pressure Effects on the Orbit Motion at SEL2 for the James Webb Space Telescope," AAS/AIAA Astrodynamics Specialist Conference, 2019.

Questions?