An Independent Orbit Determination Simulation for the OSIRIS-REx Asteroid Sample Return Mission

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K. Getzandanner*, D. Rowlands†, E. Mazarico†,
P. Antreasian††, C. Jackman††, M. Moreau*

*NASA/GSFC Code595,
8800 Greenbelt Rd,
Greenbelt, MD 20771, USA.

†NASA/GSFC Code698,
8800 Greenbelt Rd,
Greenbelt, MD 20771, USA.

††KinetX, Inc., Space Navigation and Flight Dynamics Practice,
21 W. Easy St., Ste 108,
Simi Valley, CA 93065 USA.

OSIRIS-REx Flight Dynamics System

FDS Team consists of three organizations:

KinetX Space Flight Dynamics Practice

- Orbit Determination
- Optical Navigation (OpNav)
- Maneuver Planning

Lockheed Martin Space Systems Company

- Trajectory Design & Optimization

Goddard Space Flight Center

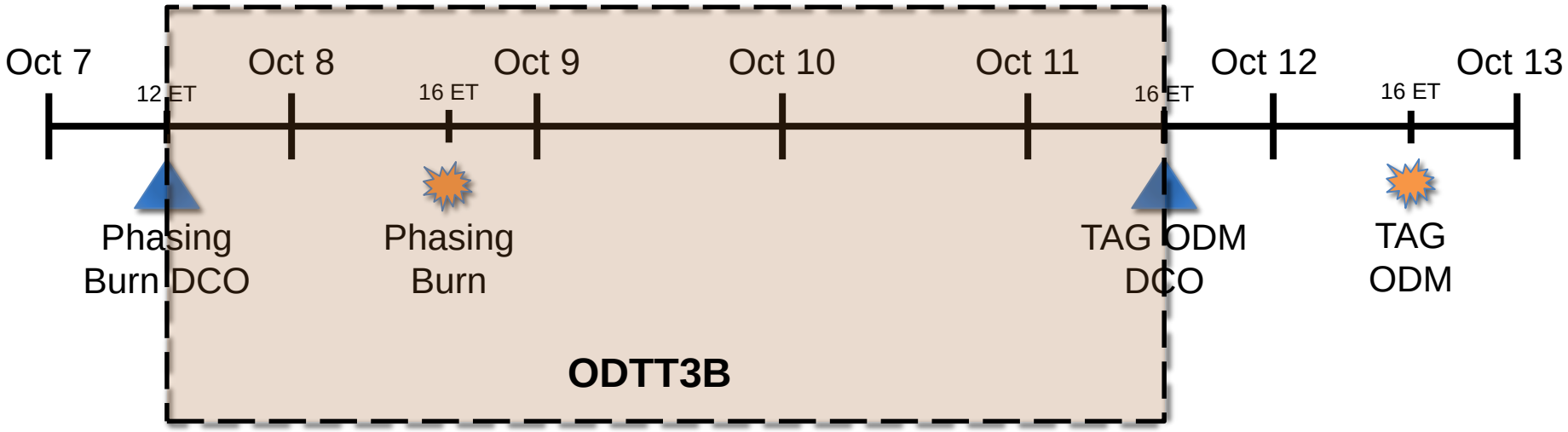
- FDS Management
- Launch Window Analysis
- IV&V of Navigation Products

Orbit Determination Thread Test 3B

- Realistic Orbit Determination & OpNav simulation of the Orbit B mission phase leading up to TAG

- Objectives:
  - Test interfaces between OD & OpNav Software
  - Verify flight dynamics requirements
  - Assess navigation performance
  - Ensure consistent results across FDS organizations

Pre-TAG Operations Timeline



ODTT3B Software

- MIRAGE
  - Operational precision OD software
  - Developed by JPL/CalTech, licensed to KinetX

Independent evaluation of ODTT3B

- GEODYN
  - Precision OD and geodetic parameter estimation software
  - Radio-science and IV&V of navigation products
  - Weighted Batch Least Squares (WBLS) Estimator
  - Developed by the GSFC Planetary Geodynamics Laboratory

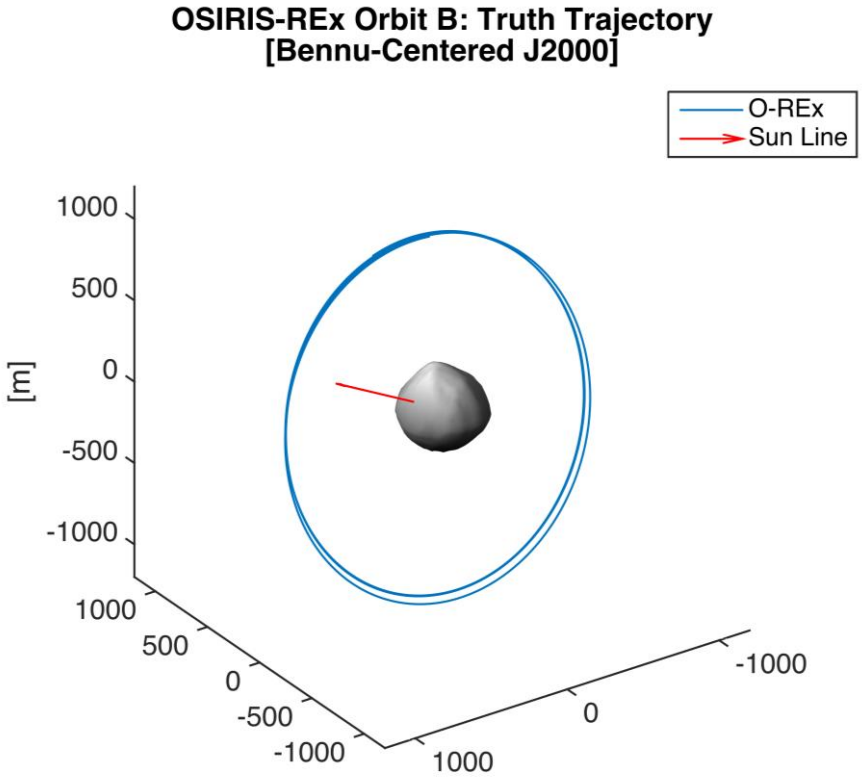
- SPC Toolkit/Lithosphere
  - Global shape model and topographic product development
  - OpNav image processing and landmark measurement generation
  - Developed by Dr. Robert Gaskell, maintained by the OSIRIS-REx SPOC at University of Arizona

ODTT3B PERTURBATIONS

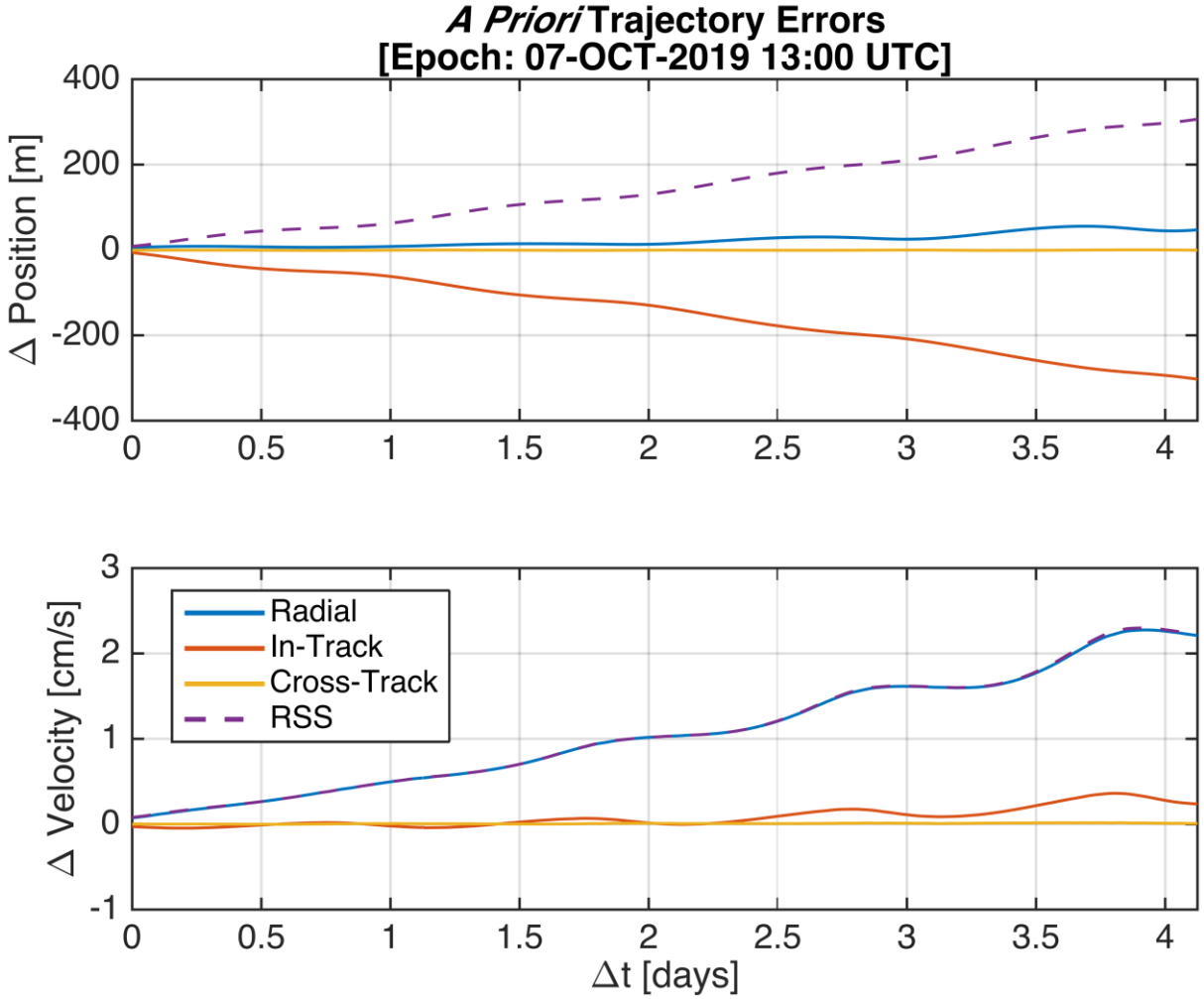
- Nominal Orbit B: 1 km radius, circular orbit in the terminator plane

- Perturbations applied to “truth” trajectory propagation:
  - Initial Spacecraft State
  - Bennu Gravitational Parameter
  - Bennu Spherical Harmonic Coefficients (up to degree/order 3)
  - Bennu Orientation (RA/Dec/Rate)
  - Phasing Maneuver ΔV
  - SRP Scale Factor
  - Spacecraft Attitude
  - Spacecraft Thermal Accelerations

- Resulted in errors >300 meters after 4 days



A PRIORI ERRORS

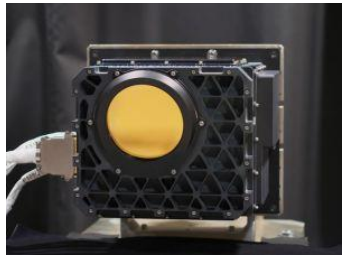


Simulated Data

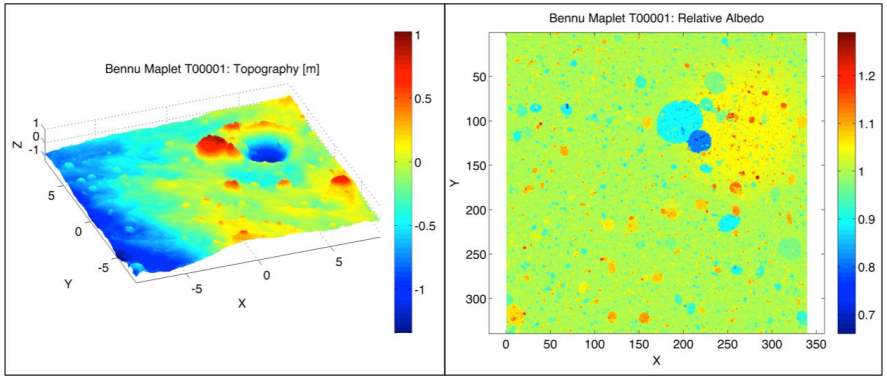
- DSN Radiometric Data
  - Daily passes (6:30am to 2:30pm UTC)
  - Range & Doppler
  - Noise: 3 meters, 0.1 mm/s (1σ)

- NavCam OpNav Images
  - One image every 2 hours (54 total)
  - Blackout Period: 3:15pm to 8:45pm UTC
  - Attitude Errors: 1.15 mrad boresite, 1.01 mrad roll (1σ)
  - Read Noise and Dark Current Added

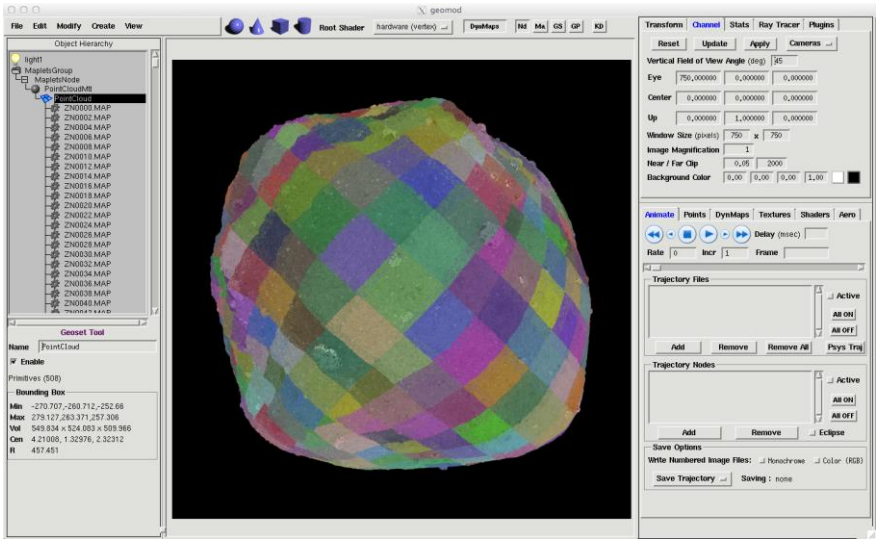
- Altimetric Range Measurements
  - Based on OSIRIS-REx Laser Altimeter (OLA)
  - Generated using a Digital Elevation Model (DEM) at 8 pixels per degree [PPD]
  - Raster Scan at 10,000 Hz

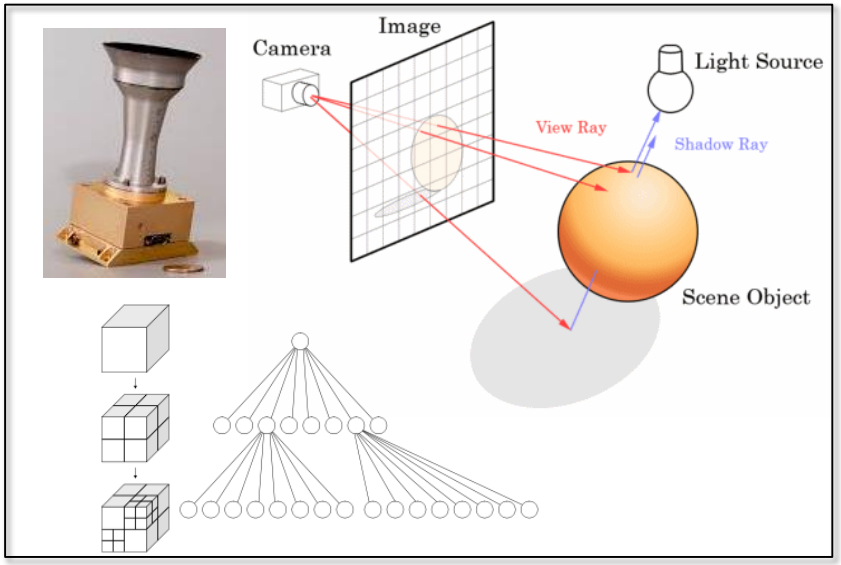


Synthetic Image Rendering



- Synthetic surface model generated at 5cm resolution
  - Based on radar-derived shape model (20 meter resolution)
- Lens and detector model based on OSIRIS-REx NavCam
- Stochastic ray-tracing of terrain data using GSFC/Freespace

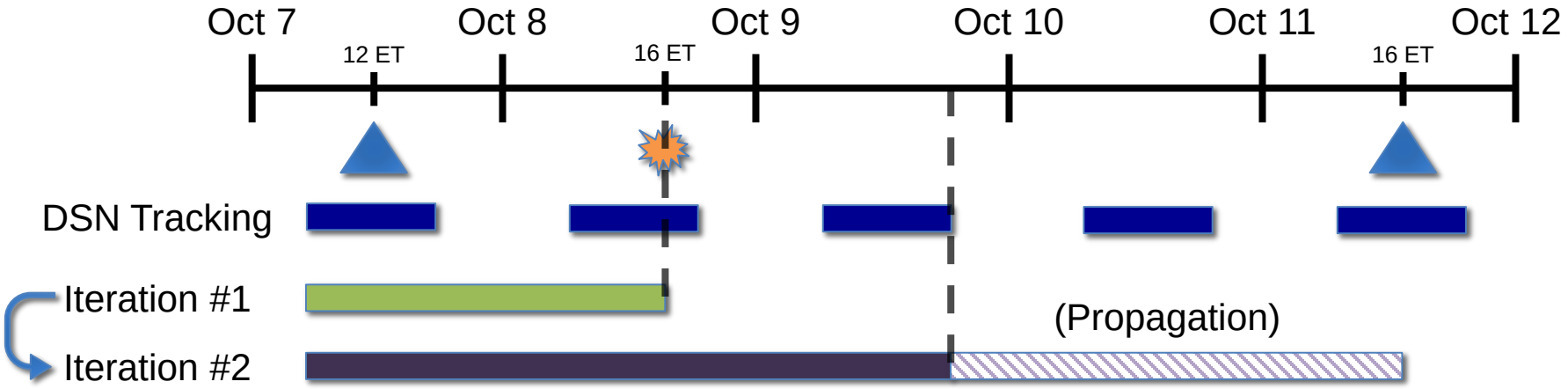




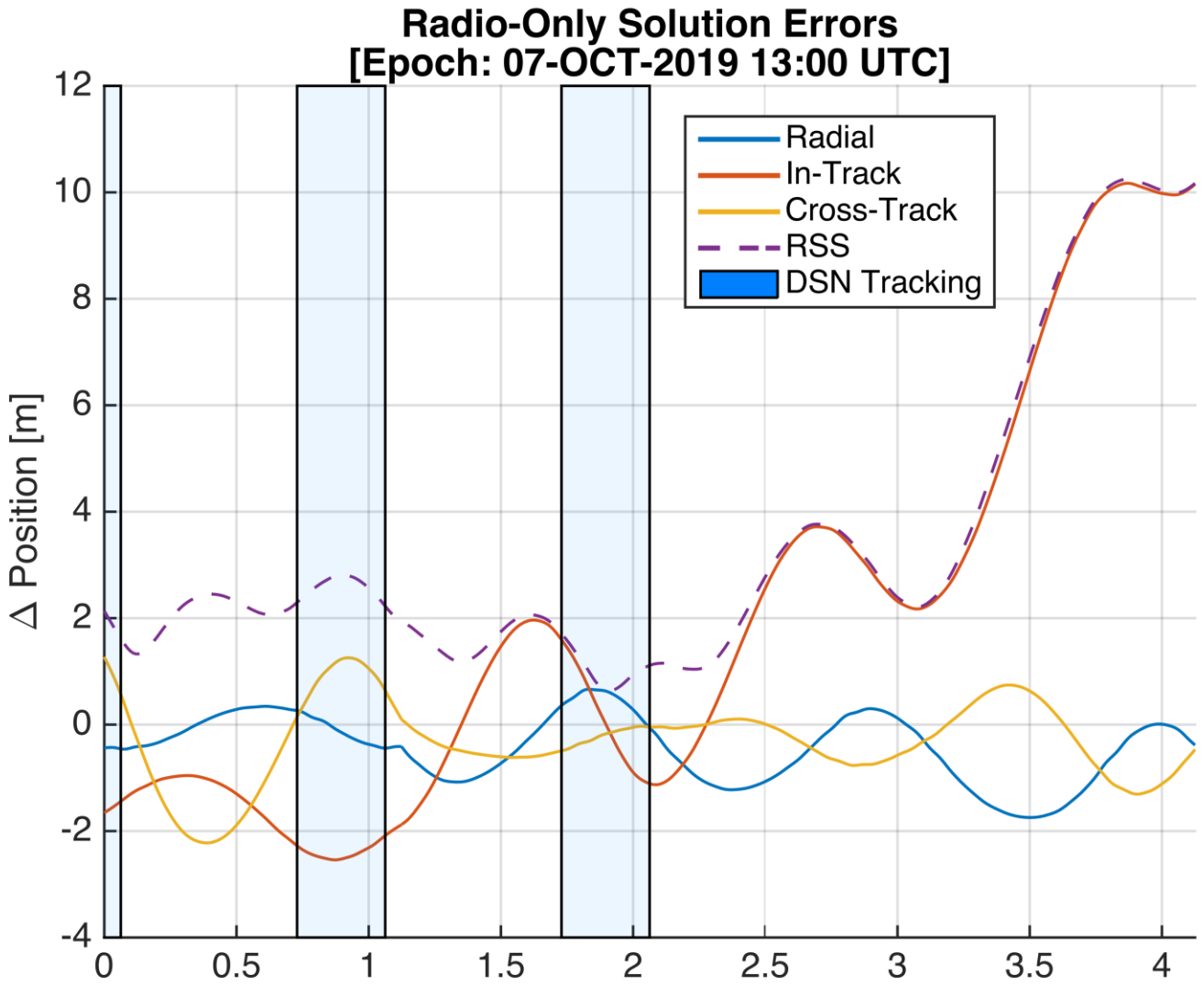
RADIO-ONLY SOLUTION (1/2)

- Performed an OD solution with radiometric data only
  - Provides a reasonable *a priori* estimate for automated image processing
- Solved in two arcs:
  - Up to (but not including) the phasing maneuver
  - Through the second DSN pass after the phasing maneuver

- Estimated Parameters:
  - Initial State
  - SRP Scale Factor
  - Phasing Maneuver ΔV
  - Constant Acceleration Bias
  - DSN Range Bias
- Bennu geophysical parameters held fixed at *a priori* values

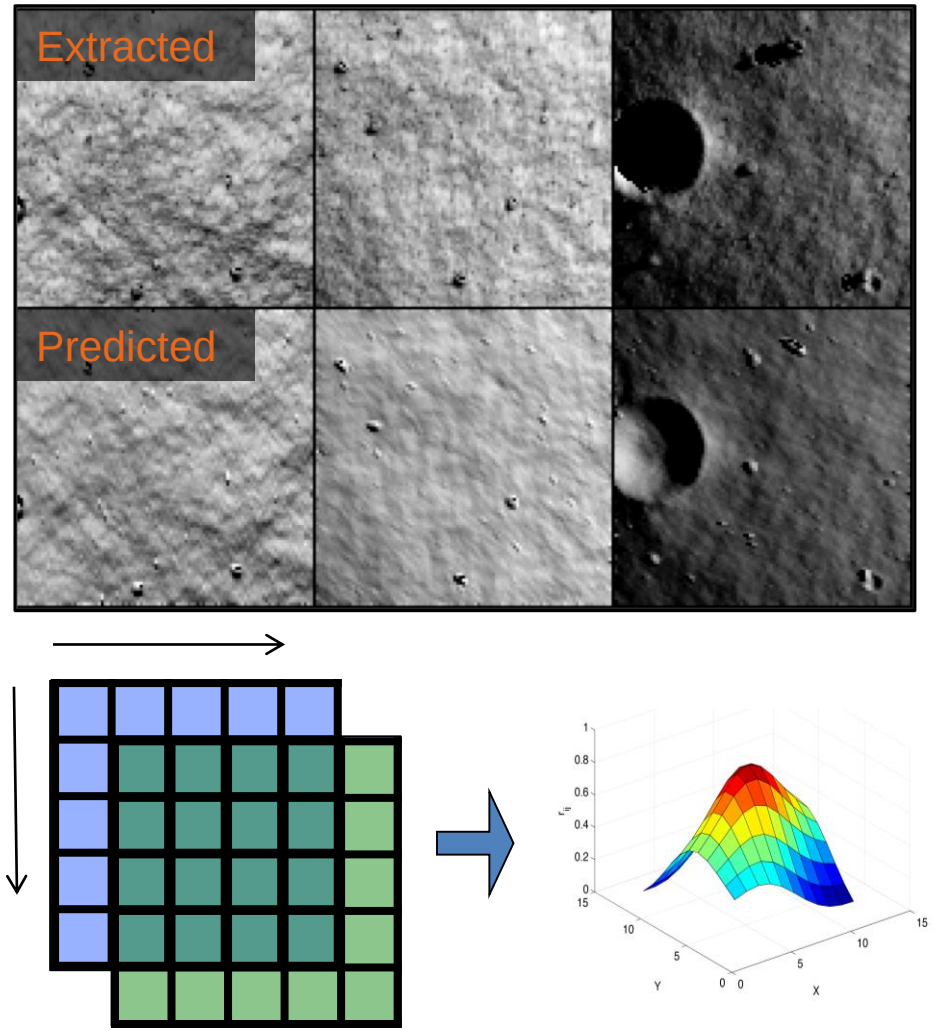


RADIO-ONLY SOLUTION (2/2)



OpNav Image Processing

- Registered topographic maps (75 cm resolution) in the OpNav images
  - Derived from 5cm global data
  - Location of the map center (aka “landmark”) is used as an OD observable
- Processed 96 landmarks in 54 images
  - Resulted in 428 OpNav Observables
  - Average shifts of ~25 pixels
- Landmark location errors of 1 meter in each axis (1σ)



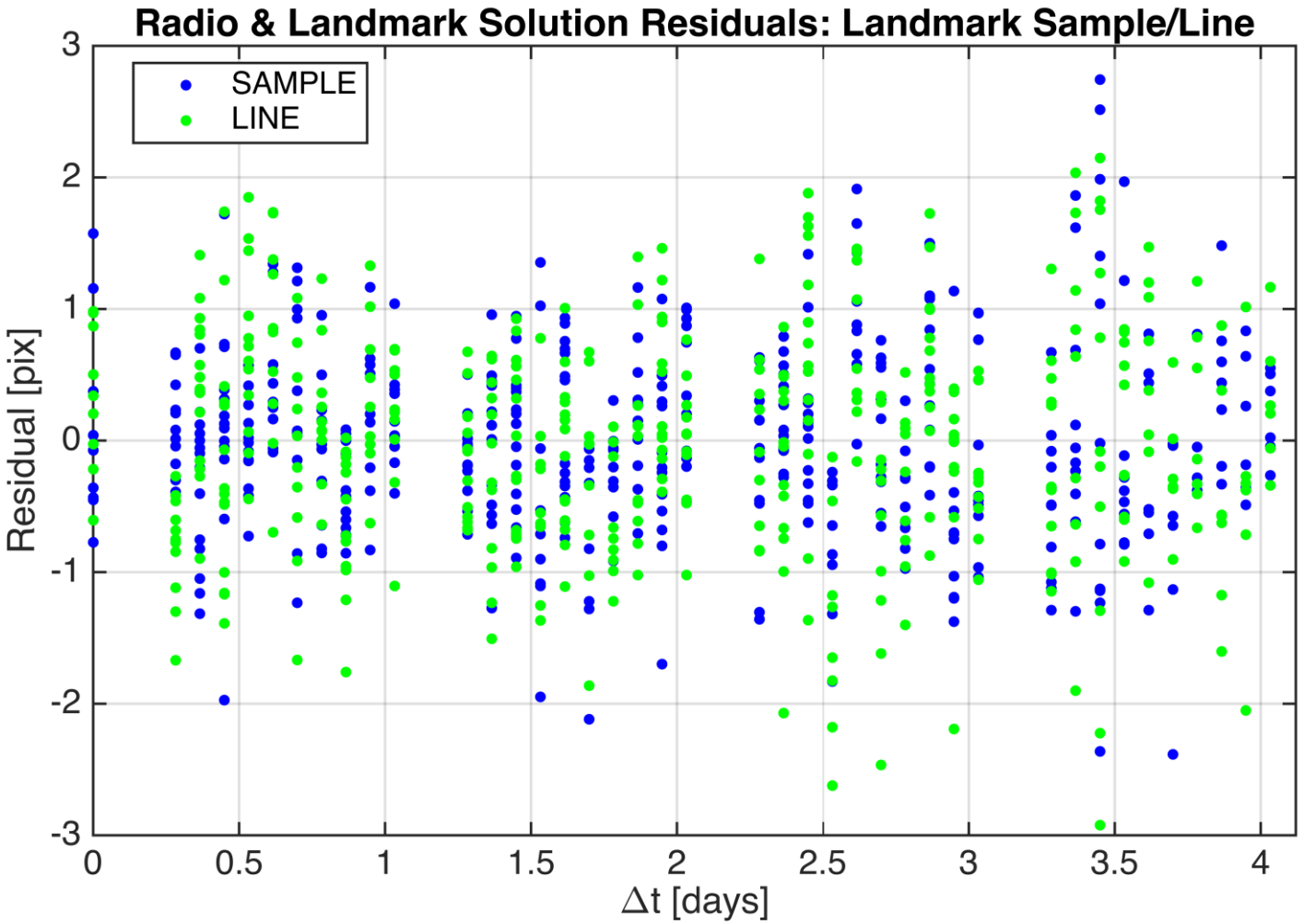
Radio + Landmark Solution (1/3)

- Re-calculated the OD solution with radiometric and landmark data
- Solved in two arcs:
  - Entire arc with geophysical parameters fixed
  - Entire arc with geophysical parameters as solve-fors
- Estimated Parameters:
  - Initial State
  - SRP Scale Factor
  - Phasing Maneuver ΔV
  - Constant Acceleration Bias
  - DSN Range Bias
  - Camera pointing at each image epoch
  - Bennu-Fixed Landmark Locations
  - Bennu Geophysical parameters

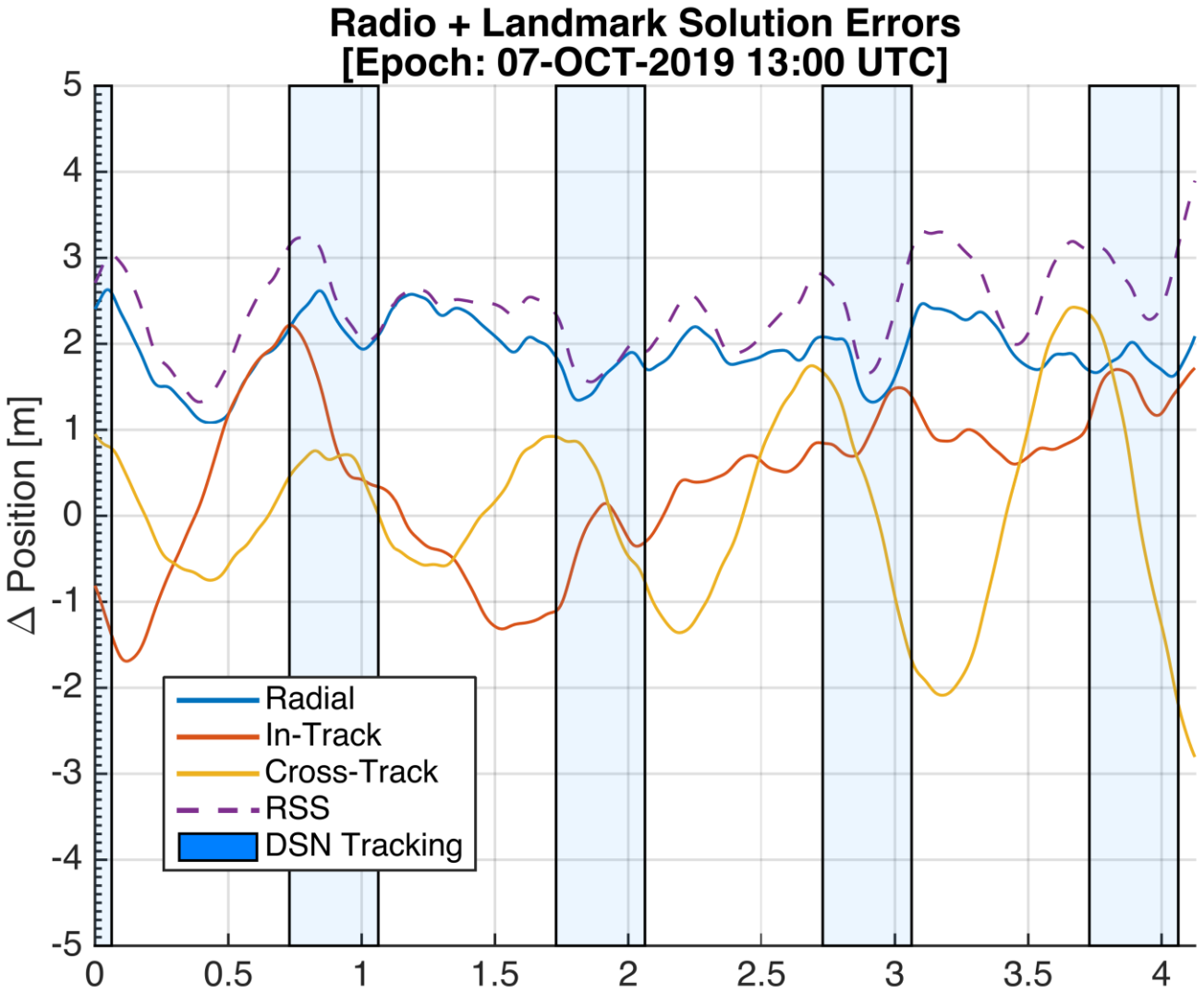
Final solution measurement residual statistics:

Measurement	Weight	Number	Mean	RSS
Range (RU)	24.5	188	0.00	21.89
Doppler (Hz)	0.0056	1738	0.0003	0.0059
OpNav, Total (pix)	0.45	428	-0.0234	0.8398

RADIO + LANDMARK SOLUTION (2/3)



RADIO + LANDMARK SOLUTION (3/3)



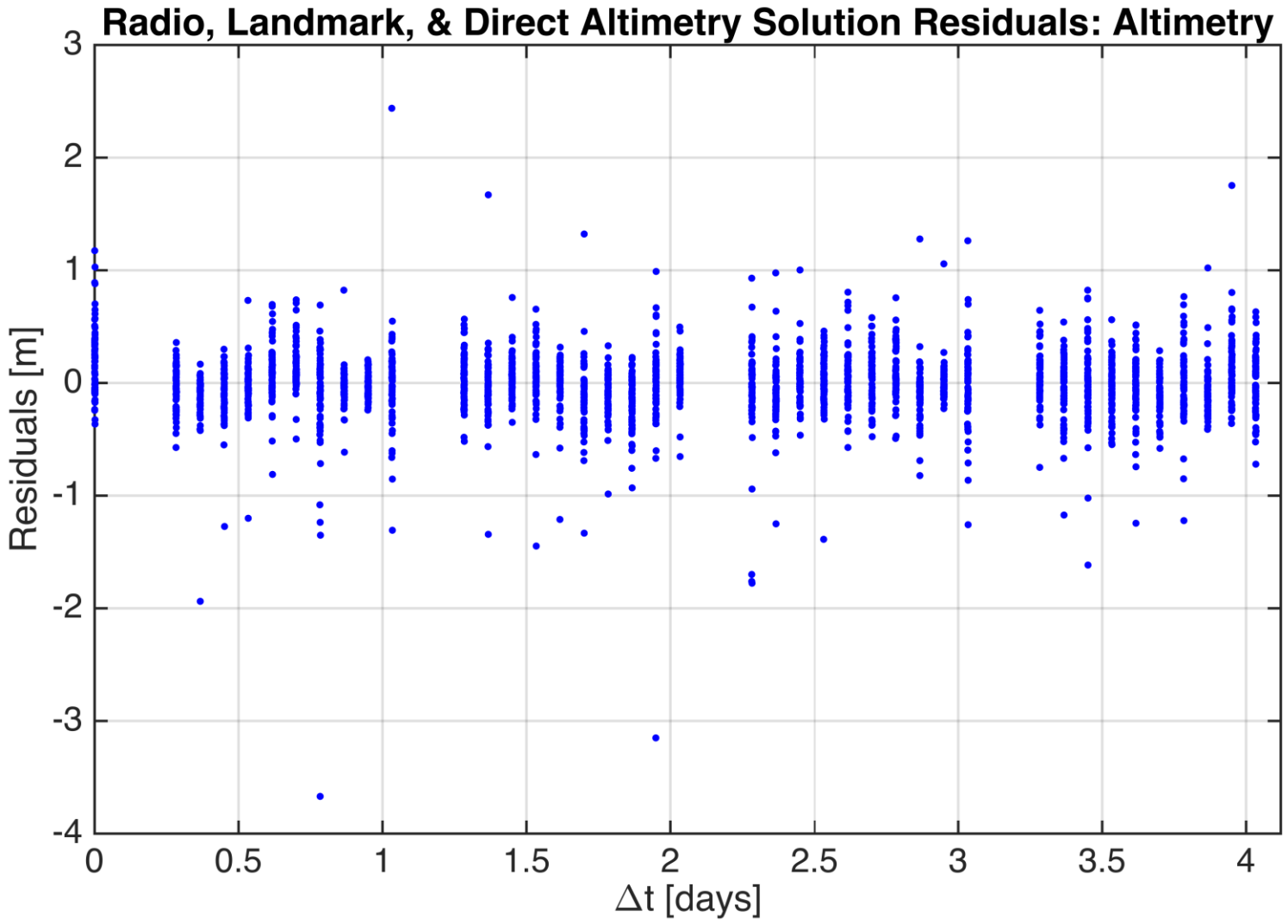
Adding Altimetry Data (1/3)

- Re-calculated OD solution with radiometric, landmark, and altimetric range data
- Used a 1 PPD DEM to compute predicted measurements
  - 8 PPD used for “true” measurements
- Same solve-for parameters and filter strategy as before
- Showed a modest improvement in trajectory solution and improved geodetic parameter estimation (particularly Bennu GM)

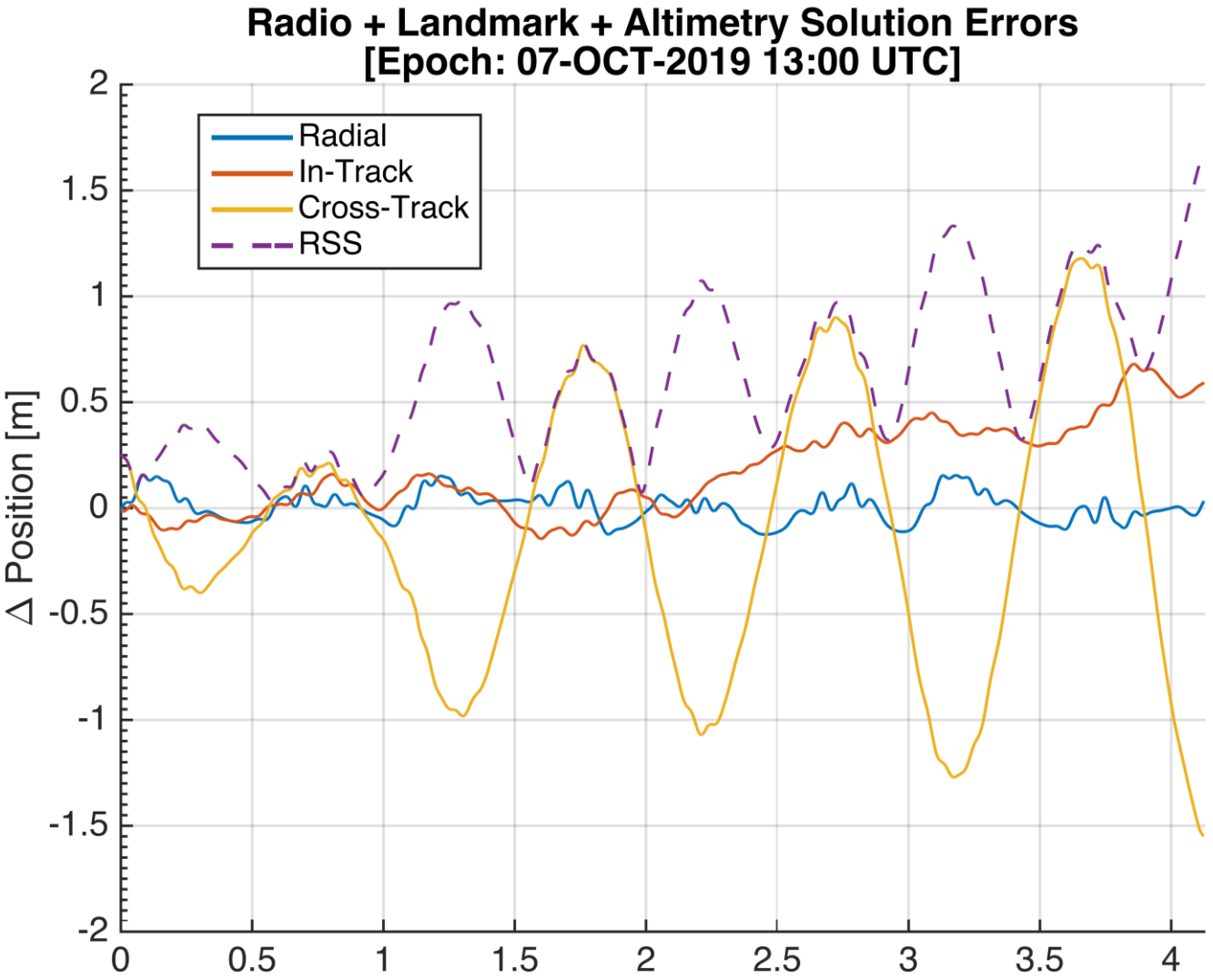
Final solution measurement residual statistics:

Measurement	Weight	Number	Mean	RSS
Range (RU)	24.5	188	0.00	21.28
Doppler (Hz)	0.0056	1738	0.0014	0.0061
OpNav, Total (pix)	0.45	428	-0.0729	0.8361
Altimetric Range (cm)	15	2667	-0.85	29.5

ADDING ALTIMETRY DATA (2/3)



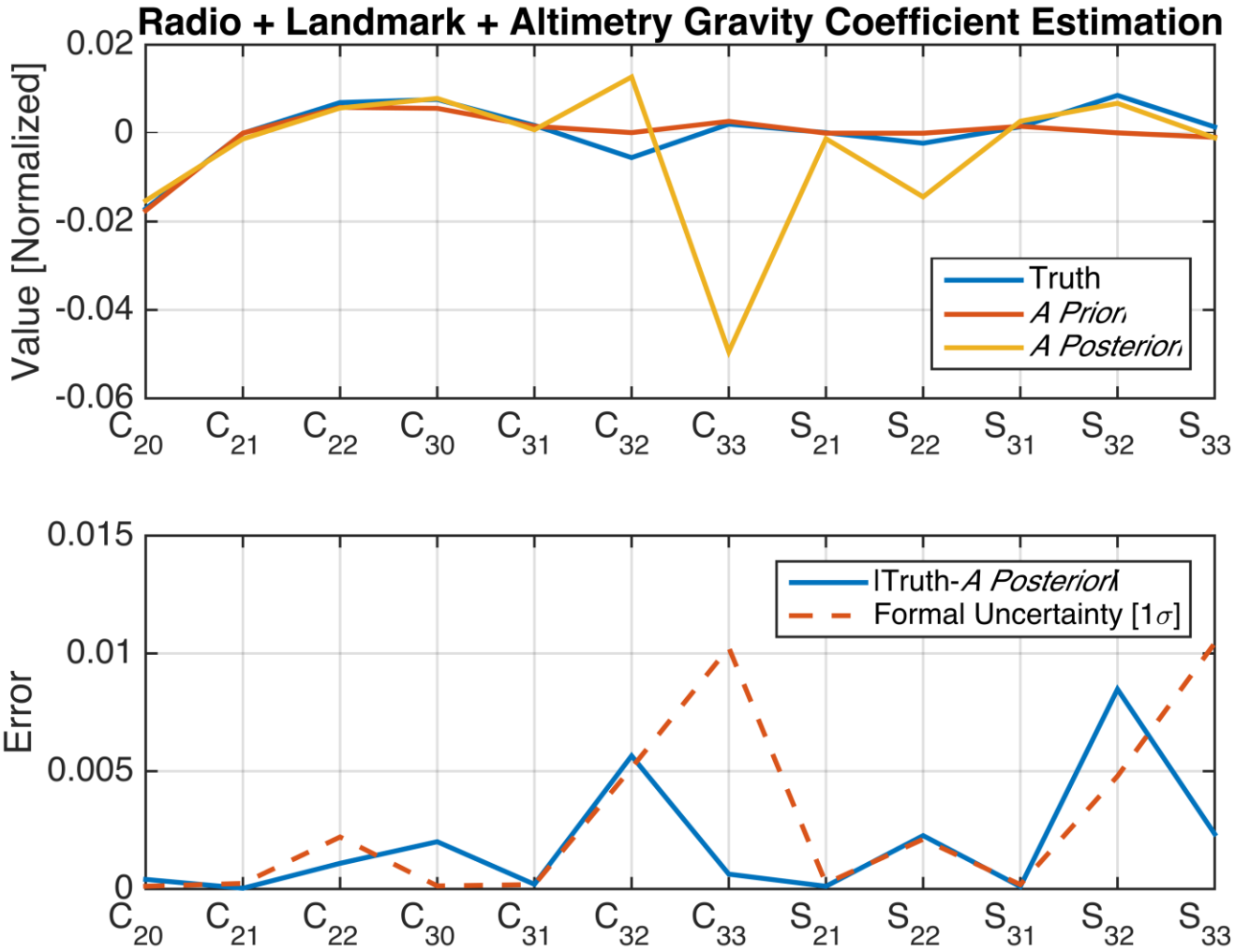
Adding Altimetry Data (3/3)



Bennu Geophysical Parameter Estimation (1/2)

		Without Altimetry		With Altimetry	
Parameter	**Truth**	**A Posteriori**	**Formal σ**	**A Posteriori**	**Formal σ**
GM, μ (m3/s2)	5.1969	5.1626	1.490e-03	5.1954	1.059e-03
RA, α (deg)	86.6388	86.5730	8.772e-03	86.6205	7.8676e-04
Dec, δ (deg)	-65.1086	-65.1207	4.995e-03	-65.1165	8.8772e-04
Constant, ω0 (deg)	89.6456	89.6454	1.000e-02	89.6453	1.000e-02
Rate, ω (deg/day)	2010.489449	2010.489433	4.924e-11	2010.489404	1.6078e-11

BENNU GEOPHYSICAL PARAMETER ESTIMATION (2/2)



SUMMARY

- Successfully completed an independent OD and OpNav simulation of the Orbit B mission phase
  - Interfaces between OD and OpNav software worked properly
  - Refined procedures and solution strategies
  - Definitive solution accuracy of <4 meters
  - Consistent solutions across FDS software and organizations
- Verified that short-arc solutions are not favorable for geophysical parameter estimation, but trajectory still meets requirements
  - Expected for a four-day arc with realistic perturbations to the dynamics
  - Will rely on a nine-day, uninterrupted radio-science campaign at the beginning of Orbit B
- Incorporating altimetry data resulted in a modest improvement in solution accuracy, notably:
  - Radial component of the trajectory
  - Bennu geophysical parameters (specifically GM)