Orbit Prediction for space debris tracking using laser ranging and angular data from encoder for Geochang DLT system

2018. 11. 09

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Outline

Environment and Objective

Environment

Geochang SLR System is under test operation

Debris Laser Tracking (DLT) system will be developed until 2020

Tracking Space debris by DLT (One Station Tracking)

- Using TLE information for space debris acquisition/tracking

- Guide telescope (35min by 25min) can assist when sun-illuminated and visible time to acquisition space debris depending on operating condition and skill

Objective

Considering Time Critic/Sparse measurement Scenario

Predicting accurate orbit ephemeris of space debris to avoid collision event

- Accurate 1 day OP would be needed using only 1 day 3 passes window measurement data

Issues and Related Works

Issues of space debris tracking with laser ranging

1. Inaccuracy of initial orbit state → Limitation of Observation (Acquisition / Time)

- Only using TLE information (1 km position error) for debris acquisition → sparse measurement

  Order of tens to hundreds of arcseconds

- EO Sensor/Guide telescope (sun-illuminated and visible) is needed due to narrow laser beam

2. Range measurement error → Poor OP accuracy only using range measure

- Uncertainty of debris size and attitude brings these errors

  Ref. Use of laser ranging to measure space debris, Zhang, Yang et al

- Graz : 0.7m, Shanghai : 0.6 ~0.8m, Mt. Stromlo : better than 1.5 m RMS

  Ref. Laser measurement to space debris from Graz SLR station, Kirchner, Koidl et al

- OD/OP only using range measurement brings limits in the achievable accuracy

  Ref. Fusion of laser ranges and angular measurement data for LEO and GEO Space debris OD, Cordelli, Vananti et al

Related Works

Range + other data (angular data of other optical system, TLE generated position…)

Ref. Real time OD Method for smooth transition from optic to laser, Li, Sang, Zhang et al

- Other data also have measurement error (angular of EO : 2 ~ 5”, TLE Generated : hundreds of meter)

  Ref. very short arc OD for low Earth object using Sparse optical and laser data, Bennett, Sang et al

- Improve OP accuracy and make unaided laser ranging possible (Below 20 arcseconds)

* at least 50% of pass could be acquired with a diverged laser beam → Overcome acquisition and time limitation

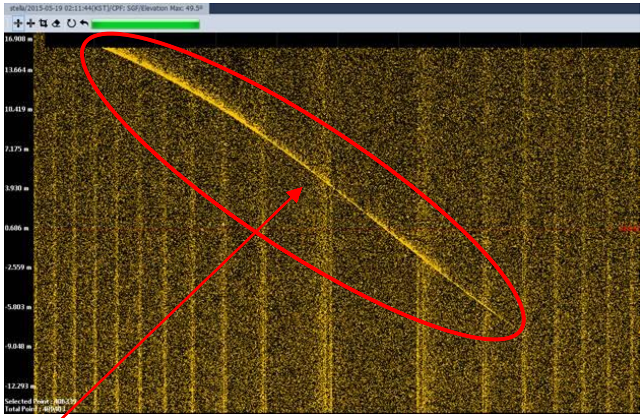
OP for Space Debris Laser Tracking

Good Measurement for OP might come from

- **Small measurement error / Small Noise**
- **Number of Observation → Enough / Dense data**
- **Geometry of observation → cover 3D position (Radial - In track - Cross track)**

Ref. Fusion of laser ranges and angular measurement data for LEO and GEO Space debris OD, Cordelli, Vananti et al

All points have each range and angular data from Encoder



Select the angular data corresponding to full-rate data after data processing

Type of data for processing

- **Optical Sensor : Angular Data**
- **Radar system : Range + Angular**
  + Range Rate
- **SLR/DLT : Range Data (Scalar)**
  + New Measurement (Geometrical)

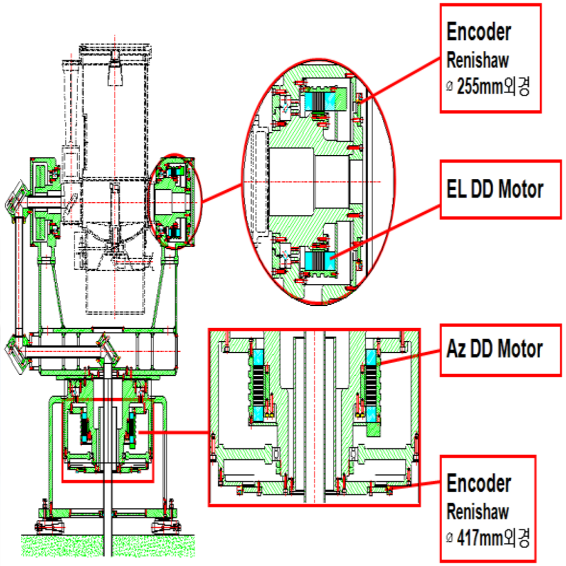
Angular data from Encoder

Encoder in Geochang system

Encoder

One of main part in Tracking Mount System to track space object

- Can measure and collect Angular data (Azimuth and Elevation)



Measurement Errors of Angular Data (Encoder)

C-SPAD FoV : 12 arcseconds

+

Pointing and tracking accuracy of TMS : 10 arcseconds

Pointing/Tracking accuracy ≤ 2 arcseconds for star

+

Time synchronization (neglectable)

About 10^{-7} sec

+

Assuming worst case error : 7 arcseconds (Unthinkable)

→ **Total 20 acrseconds (Most Worst Case)**

Considerations

Considerations

Considering Geochang DLT system Only with Range and Angular data from Encoder

Ref. OD using ODTK version 6, Vallado

Using AGI ODTK Simulation, Set Up Procedure followed by ODTK Guideline (Filter/Smoother)

Ref. Getting Started Processing SLR data with ODTK

Period of measurement : 3 Passes (only for night time) and Initial Orbit State Error : 1 km (TLE)

Gravity model : EGM08 100 by 100, Density Model : NRLMSISE-00

Targeted Space Debris : Norad ID 43031 (Apogee : 598km)

1st pass : sun-illuminated and visible time

Space Debris

Debris	InclinaCZ-2C R/B (PRC)	43031U
Expected Mass	5000kg	Cylinder
Expected Size	Radius 3.5m, length : 8m	
Area	50 Square meter	

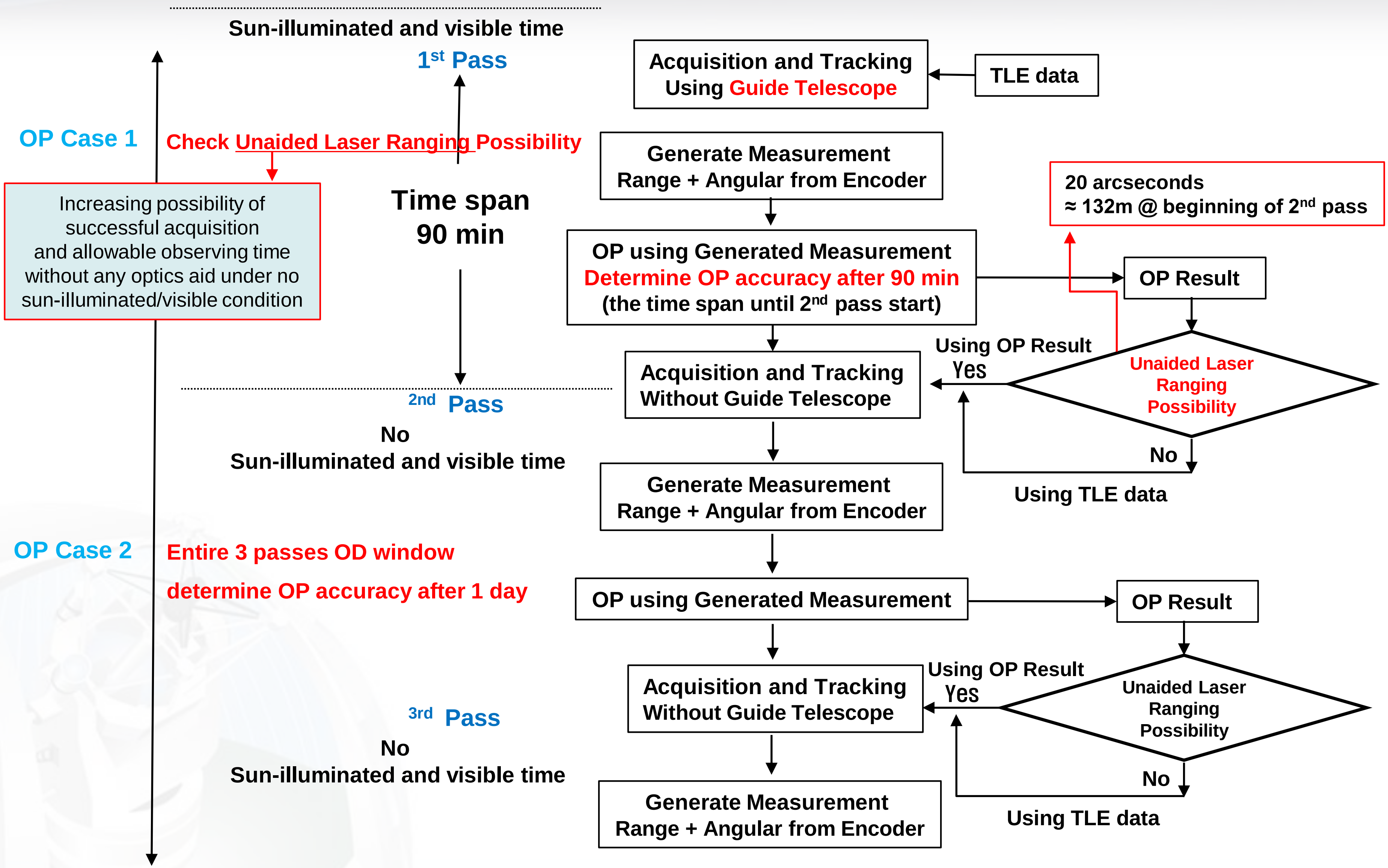
3 Pass / 1 night

Pass	Start Time (UTCG)	Stop Time (UTCG)	Duration (min)
1	29 May 2018 18:29:05.146	29 May 2018 18:33:53.986	4.814
2	29 May 2018 20:08:48.488	29 May 2018 20:14:54.599	6.102
3	29 May 2018 21:49:24.911	29 May 2018 21:55:29.110	6.07

Measurement Error and Time set up

Measurement Type	Measurement Error	Time Span
Range	Range (1m)	0.5 sec
Angular (Encoder)	20 arcseconds ≈ 0.005 Deg	0.5 sec
Angular (Electro Optic)	5 arcseconds ≈ 0.001 Deg	10 sec

Flow of Case Study



OP Case 1 (1 Pass)

140m @ beginning of 2nd pass (slant range 1450km)

OP Case 1 : Check the possibility of unaided laser ranging (20 arcseconds) of 2nd pass

Ref. very short arc OD for low Earth object using Sparse optical and laser data, Bennett, Sang et al

1-1 : Range + Angular (Encoder) / 50% of 1st pass – 90 min OP (for next pass)

1-2 : Range + Angular (Electric Optic Sensor) 100% of 1st pass → Assuming other EO sensor support

Remind

(Sun-illuminated and visible time)

1st pass with TLE / Guide Telescope/ EO Sensor

Acqusition and Tracking → OD/OP

(Assuming 50% of entire 1st pass)

If OP Accuracy is around 20"

2nd/3rd pass might do Unaided Laser Ranging

(No Sun-illuminated and visible time)

Goal

Solve limitation of Observation Issue (Acquisition and Time)

Unaided Laser Ranging

- Increasing possibility of successful acquisition and allowable observing time without any optics aid under no sun illuminated and visible condition

1. At least 50% of pass could be acquired with a diverged laser beam without other sensors (Solve the Acquisition limitation)
2. No Sun-illuminated and visible time can laser ranging (Solve the Time Limitation)

OP Case 2 (3 Passes)

OP Case 2 : Check the Range + Angular(Encoder) measurement benefit

2-1 : Range (DLT) + Angular data (from Encoder of DLT) for 3 passes

2-2 : Range (DLT) for 3 passes + Angular data (from other EO Sensor) for 1 pass (sun and visible)

→ Assuming other EO sensor support for 1 pass

2-3 : Range (DLT) for 3 passes / 1 night + Angular (Encoder) for 3 passes + Angular (EO) for 1 pass

OP Case 2-1		OP Case 2-2		OP Case 2-3
Range (DLT) + Angular data (from Encoder of DLT)	VS	Range (DLT) + Angular data (from other EO Sensor)	VS	Range (DLT) + Angular data (from Encoder) + Angular data (from other EO)

Goal Objective : Accurate 1 day OP would be needed using only 1 day window measurement data

If the OP Case 2-1 result is accurate as much as other case

→ Solve Poor OP Accuracy issue through OP with range and angular data from encoder measurement

Result of OP Case 1 (1 Pass)

How much can we trust OP result

Position Uncertainty / Position Difference /

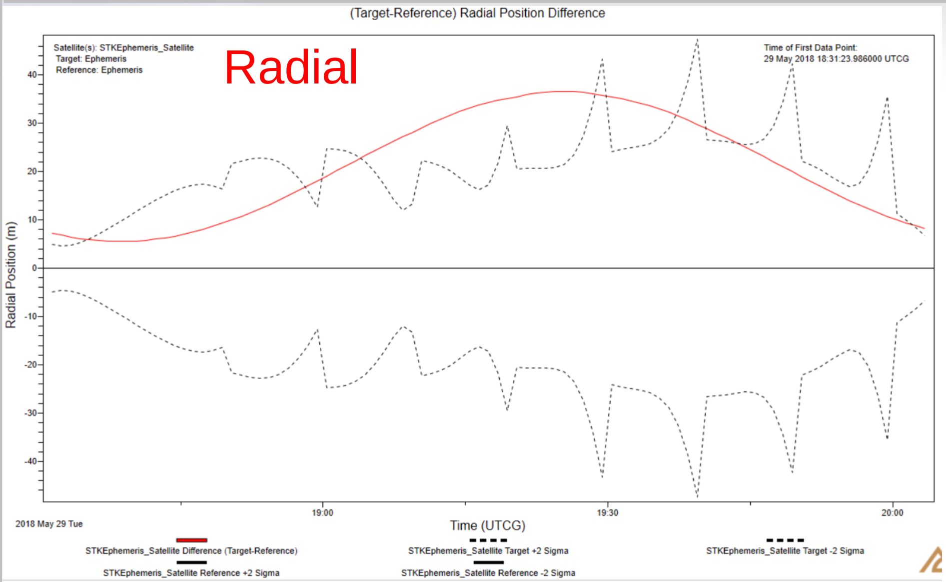
Comparison between true orbit and determined orbit (OP Accuracy)

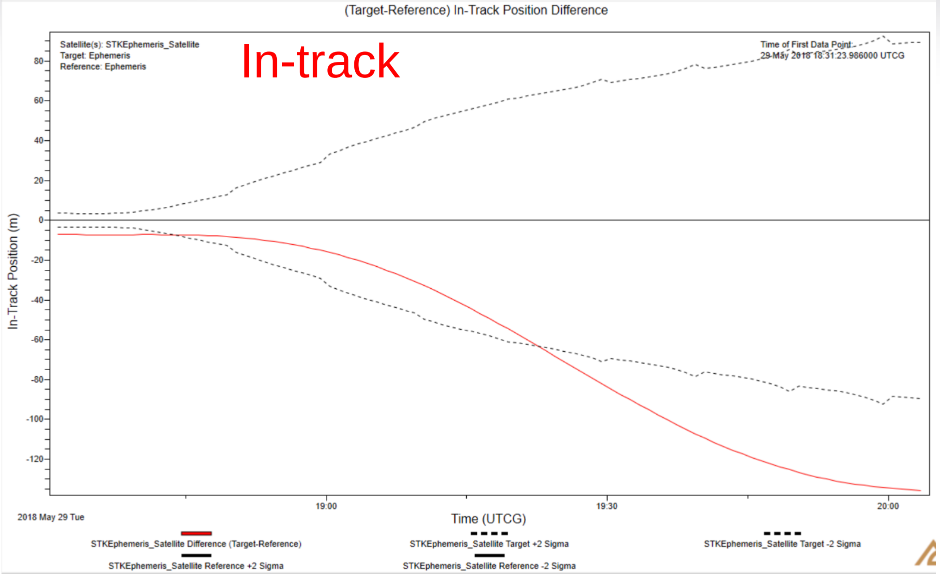
OP Result

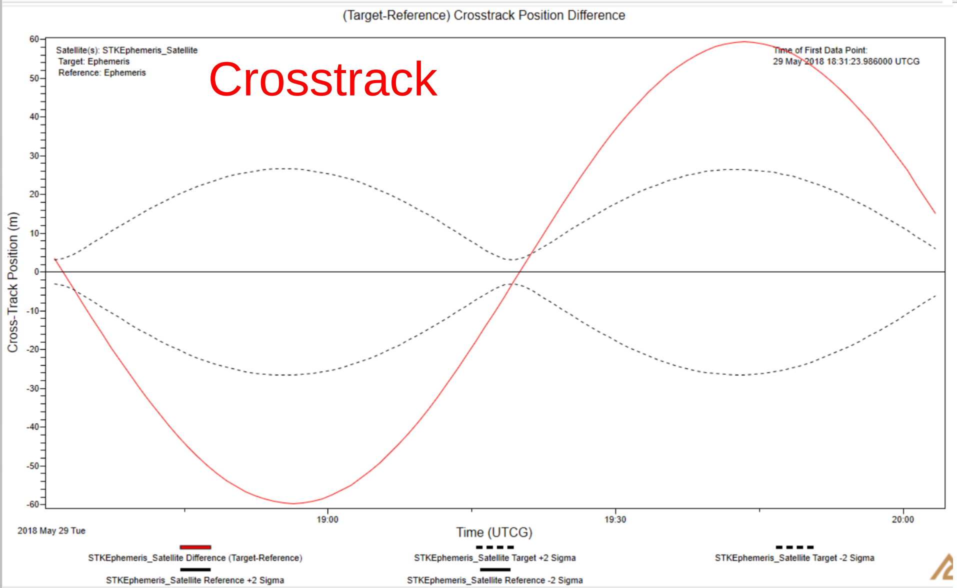
	OP Case 1 (1 Pass)	Data type	3D	R	I	C
Position Uncertainty (m) - Mean Value -	(1-1) DLT + Encoder (2m30s)	Range + Angular	2.7	1.7	1.4	1.5
	(1-2) DLT + Angular EO (5min)	Angular	10.5	5.6	6.1	6.6

	OP Case 1 (1 Pass)	Data type	3D	R	I	C
Position Difference (m) – RMS -	(1-1) DLT + Encoder (2m30s)	Range + Angular	147.4	39.6	133.6	48.2
	(1-2) DLT + Angular EO (5min)	Angular	193.1	30.3	160.9	102.4

Result of OP Case 1 (1 Pass)







DLT + Encoder (1 pass) Position Difference

More detailed view → Appendix

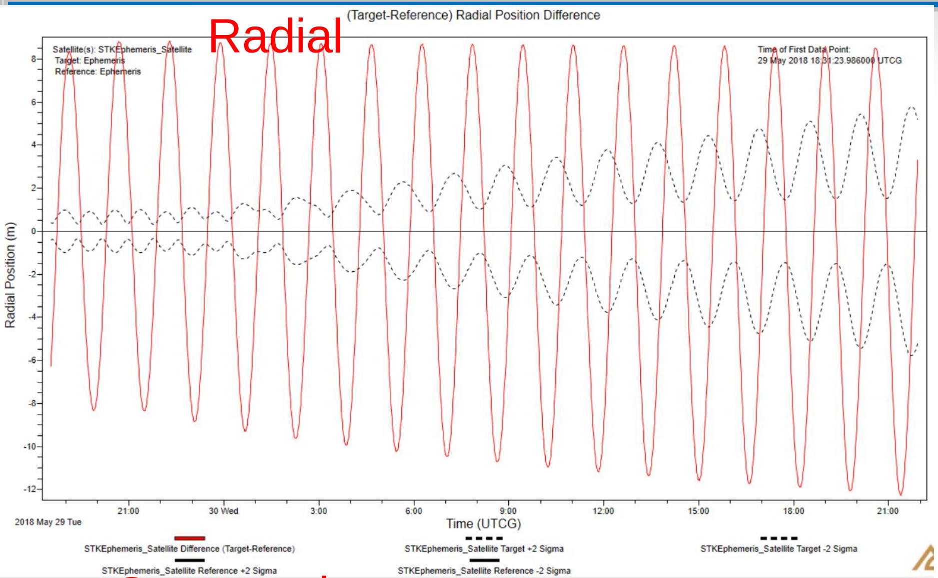
Result of OP Case 2 (3 Passes)

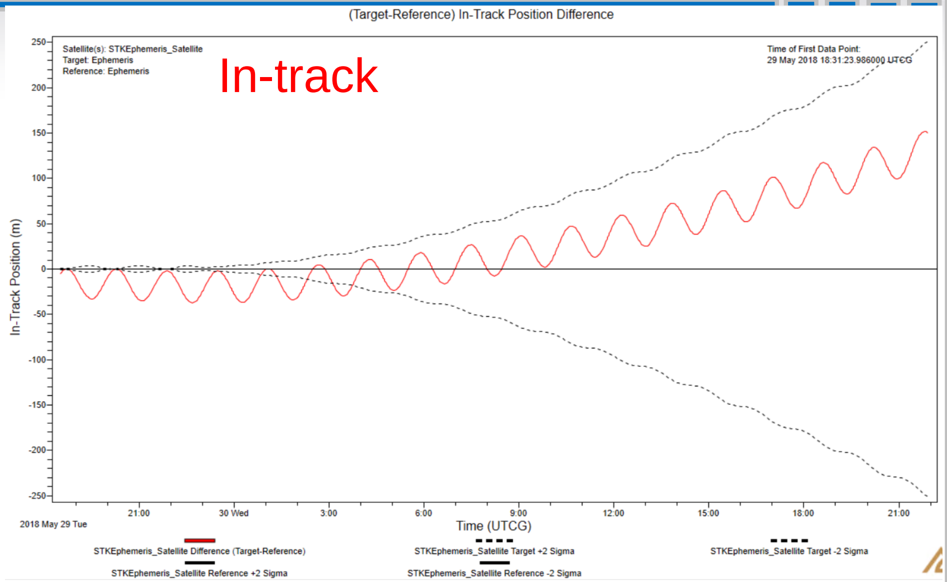
OP Result

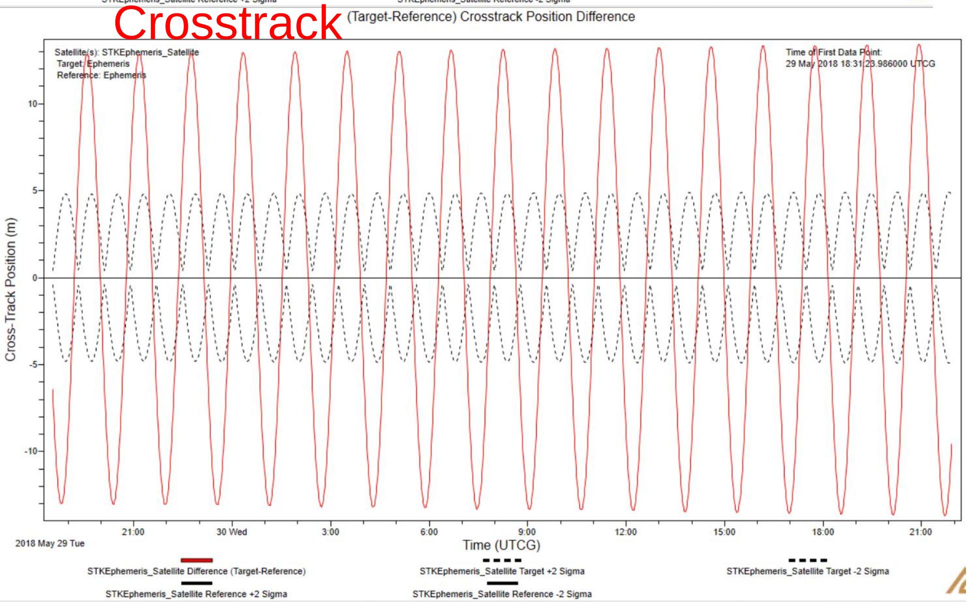
	OP Case 2 (3 Pass)	Data type	3D	R	I	C
Position Uncertainty (m) - Mean Value -	(2-1) DLT + Encoder	Range + Angular	1.2	0.2	0.3	1.16
	(2-2) DLT + Angular EO	Range + Angular	3.1	0.5	0.6	2.9
	(2-3) DLT + Angular Encoder + Angular EO	Range + Angular	0.5	0.09	0.1	0.4

	OP Case 2 (3 Pass)	Data type	3D	R	I	C
Position Difference (m) – RMS -	(2-1) DLT + Encoder	Range + Angular	56.8	6.8	55.6	9.3
	(2-2) DLT + Angular EO	Range + Angular	98.9	3.3	94.3	29.7
	(2-3) DLT + Angular Encoder + Angular EO	Range + Angular	35.5	2.4	35.4	1.2

Result of OP Case 2 (3 Passes)







DLT + Encoder (3 Pass) Position Difference

More detailed view → Appendix

Conclusion

Geochang Debris Laser Tracking Operation

Objective

Predicting accurate orbit state of space debris to avoid collision event

- Accurate 1 day OP would be needed using only 1 day 3 passes measurement

Issues

Limitation of Observation (Acquisition / Time) + Poor OP accuracy using range measurement

Solution

Novel Idea : Using Angular Data from Encoder of DLT with Range data

Results

Much better than TLE

OP Accuracy OP Case 1-1 : 147.4 m

(20" ≈ 140m @ beginning of 2^{nd} pass)

Limit of Observation (Acquisition / Time) issue

→ Increasing possibility of Acquisition and Laser Ranging Time without optics aid

Poor OP Accuracy issue → Improve OP (1 day) accuracy as much as other cases

OP Accuracy OP Case 2-1 : 56.8 m)

Preliminary Study is Completed → Go to Future Work

Future Work

1. System Implementation to extract encoder value in Geochang SLR station

2. Validation of Encoder Angular Data Measurement from real observing data (Ajisai, Satellite POD available)

3. OP with real observation data (Range and Angular) Using Geochang SLR

- OP using 1 pass measurement data (Unaided Laser Ranging Check)

- OP using 3 pass measurement data (OP Accuracy improvement Check)

- OP with other EO sensor data (Bohyun Mt. OWL EO system)

- Comparison with Simulation Result

Thanks for your attention !!!

Any Question ???

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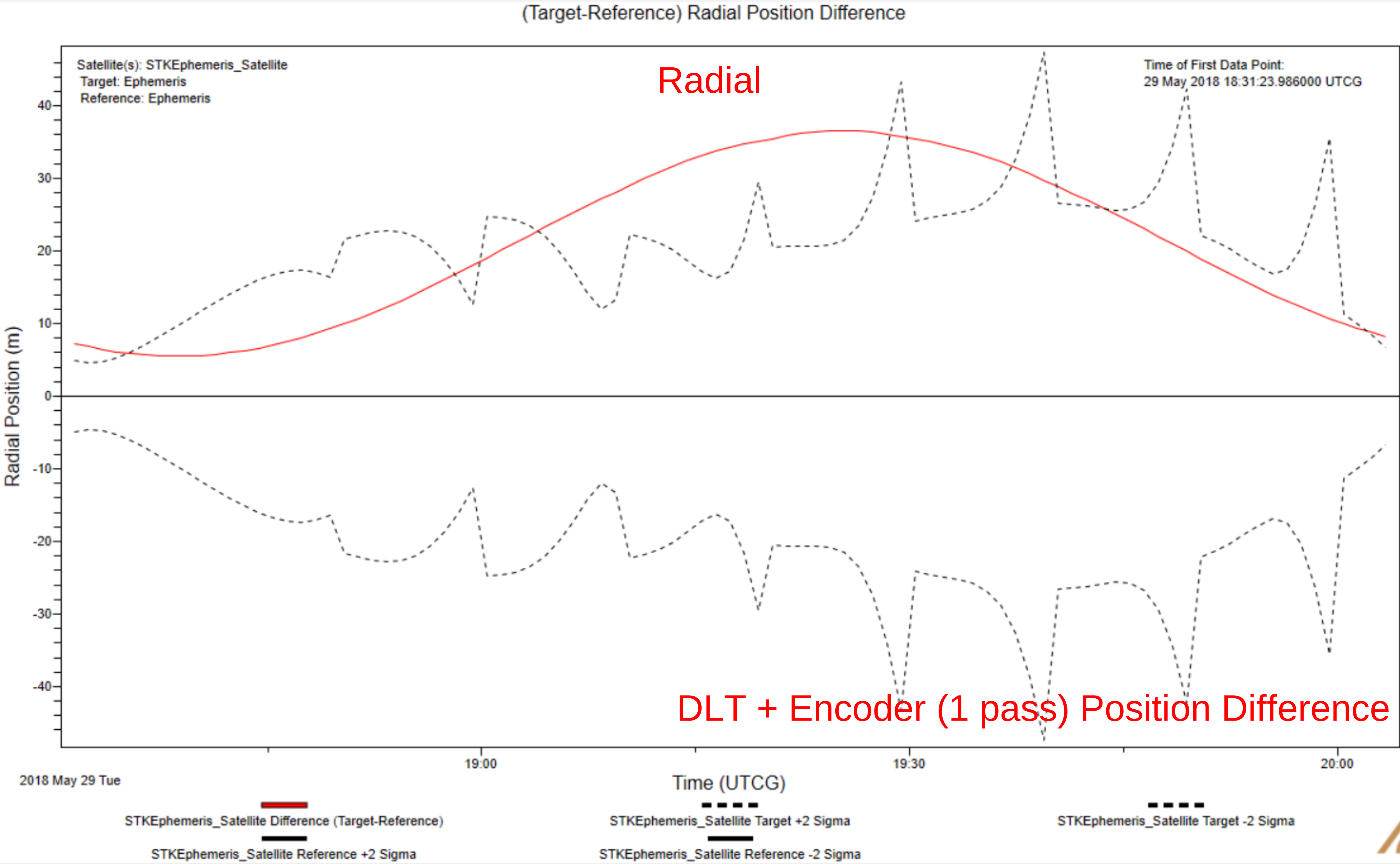
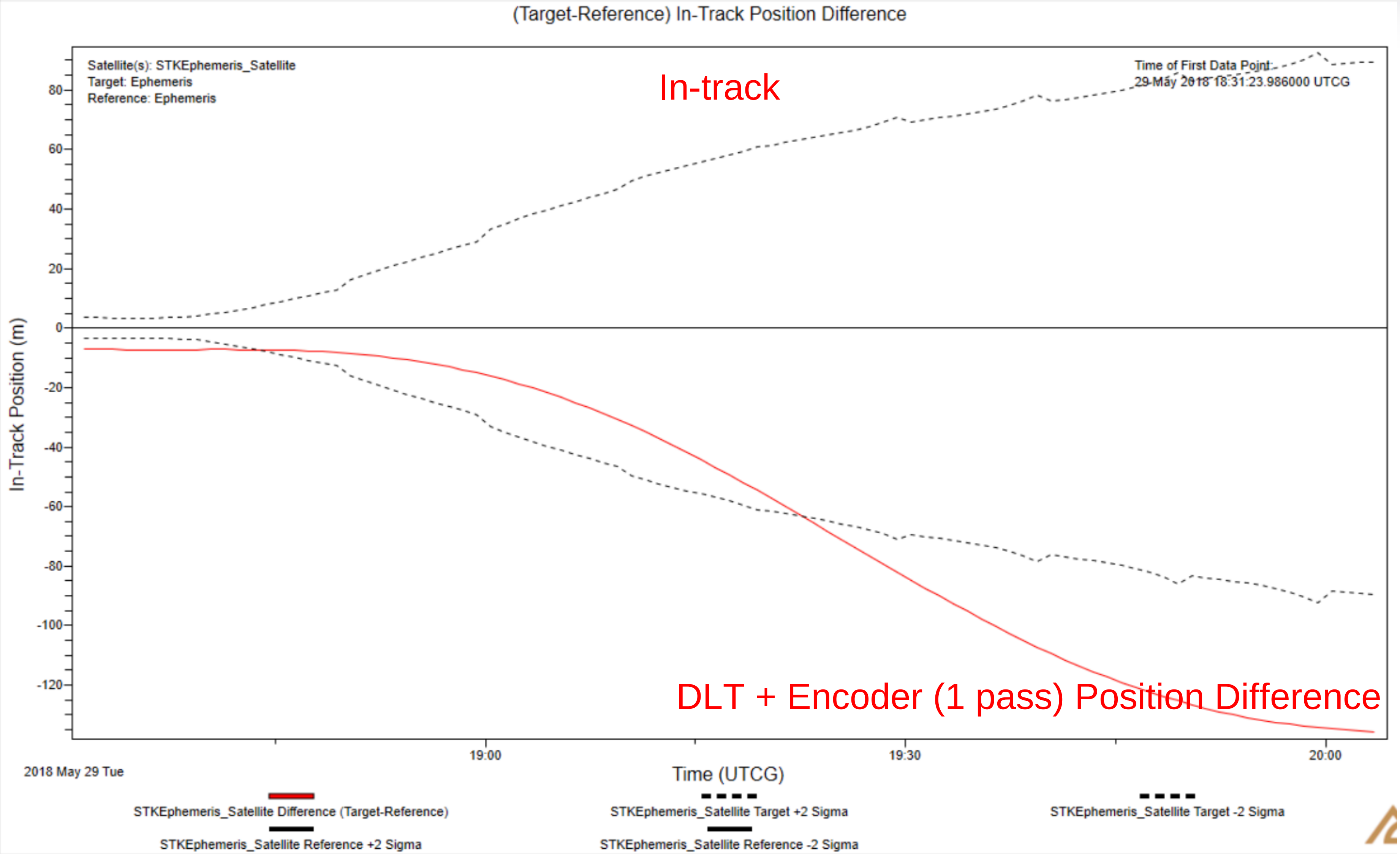
Appendix

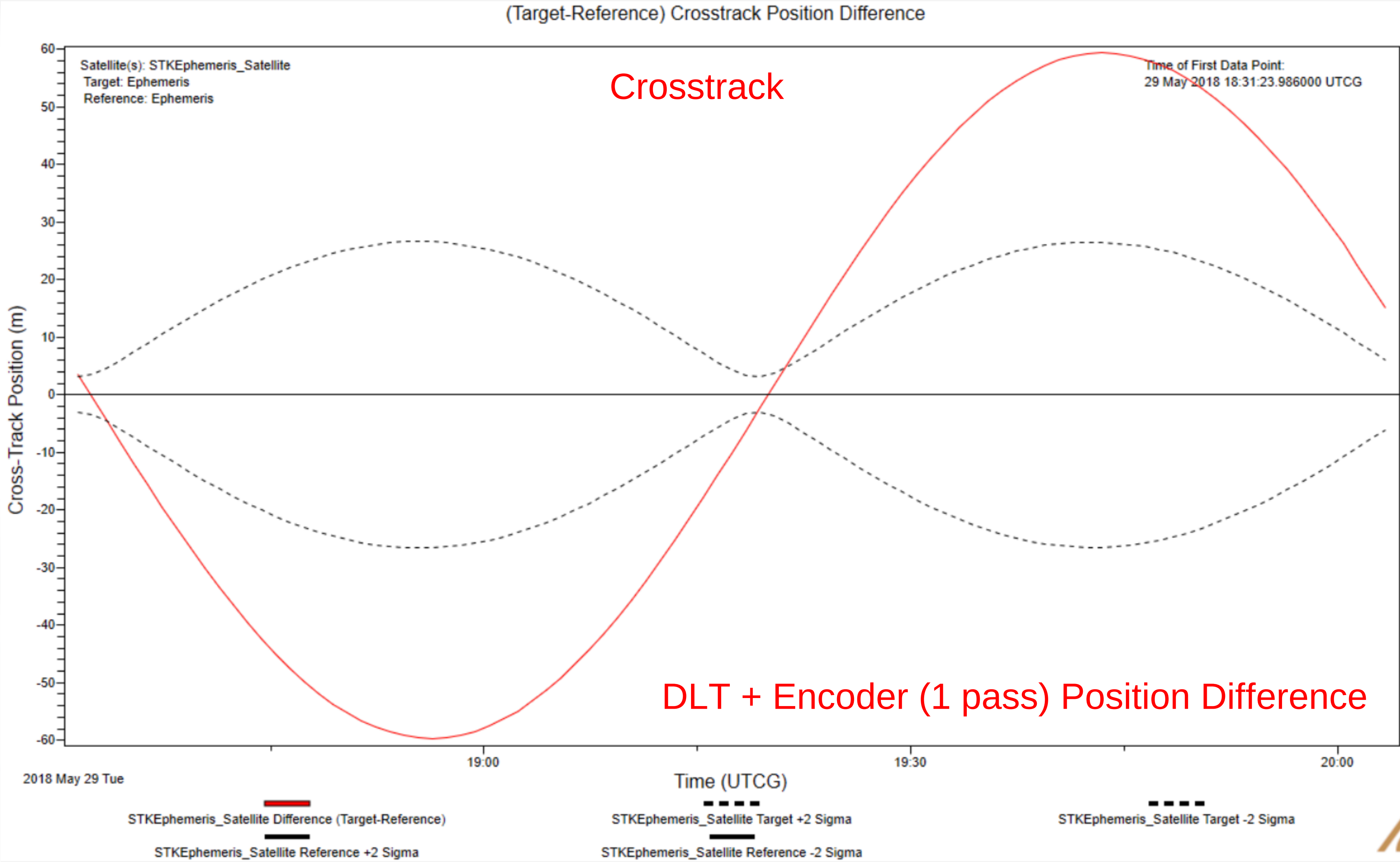
Result of OP Case 1-1



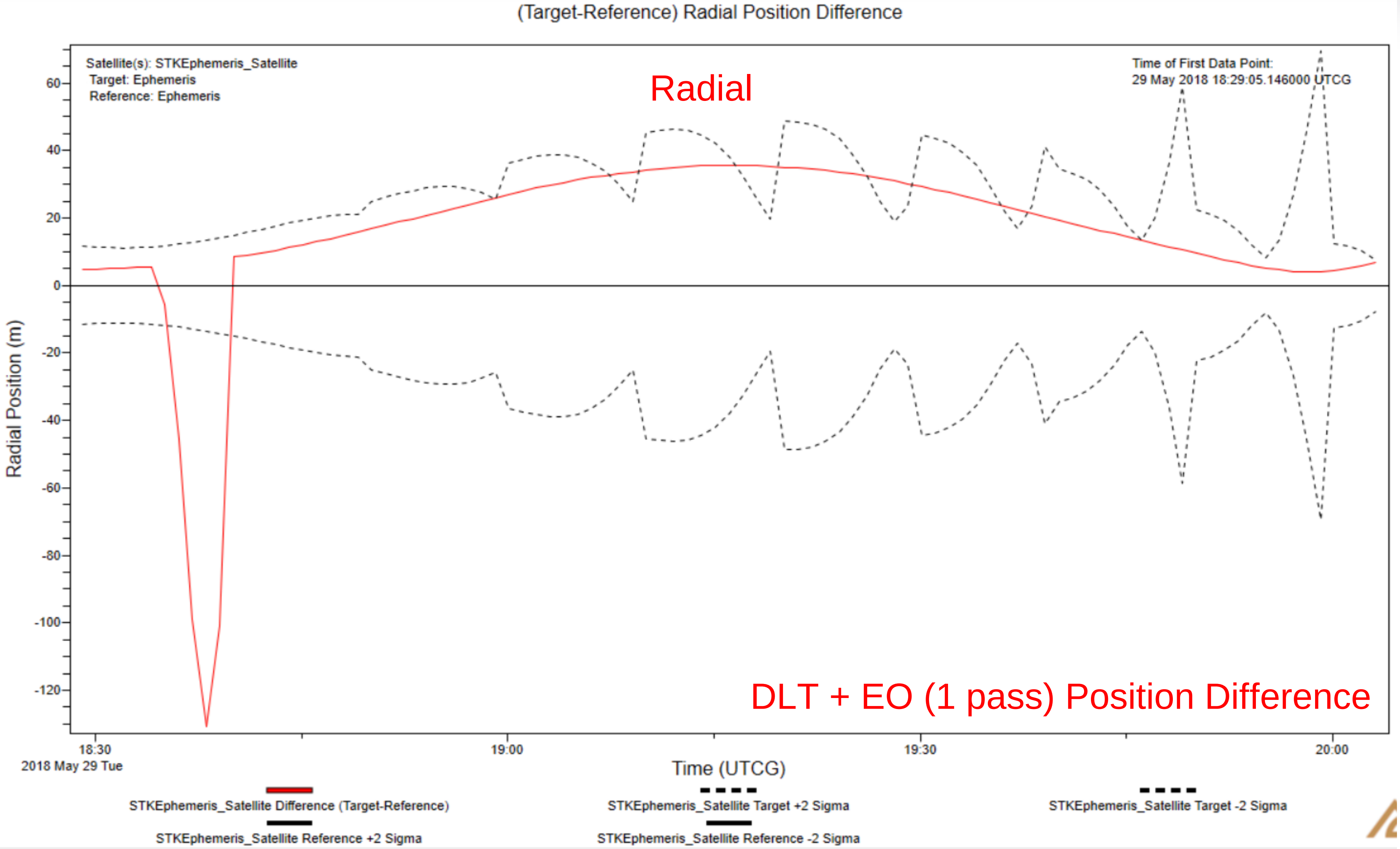
Result of OP Case 1-1



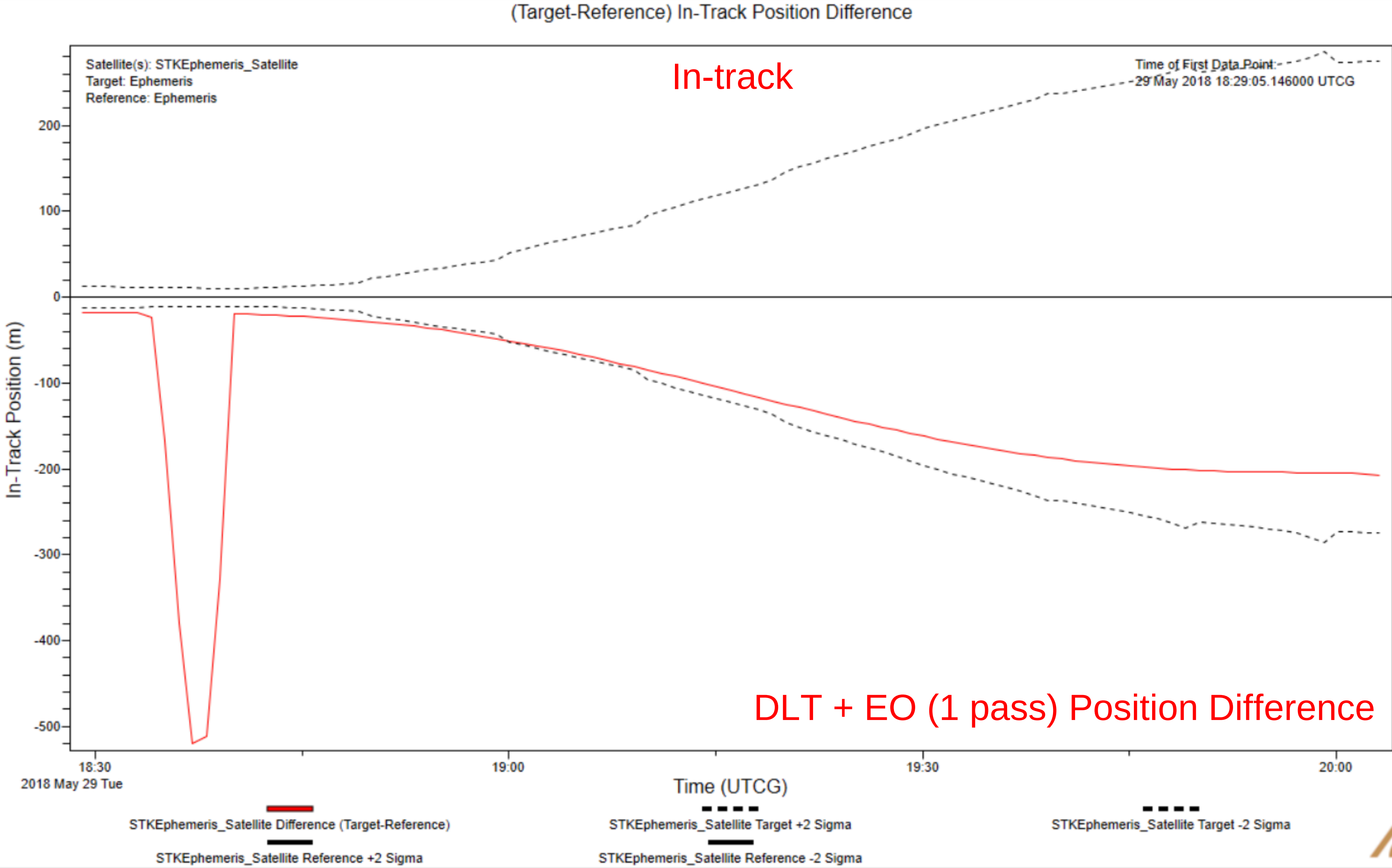
Result of OP Case 1-1



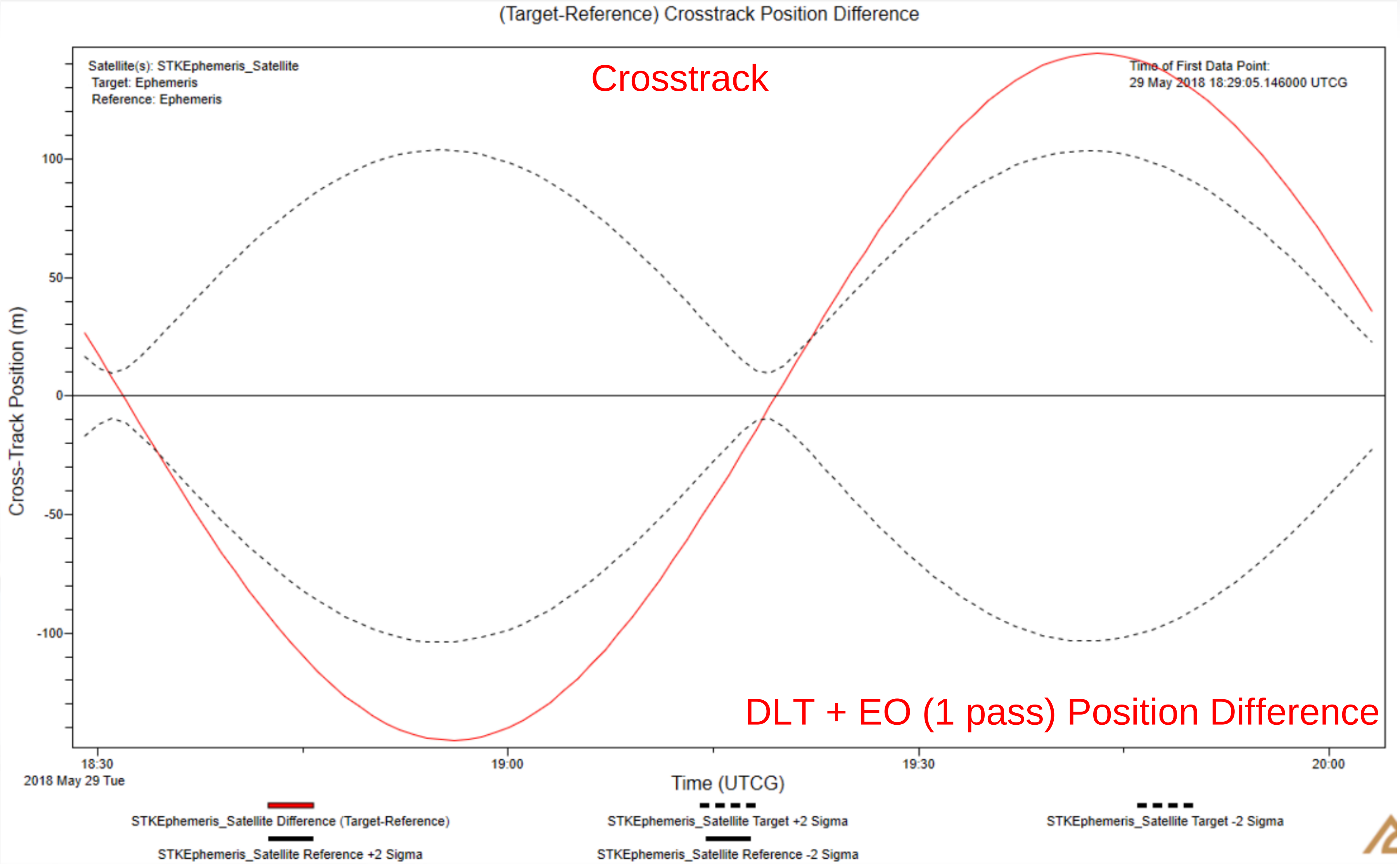
Result of OP Case 1-2



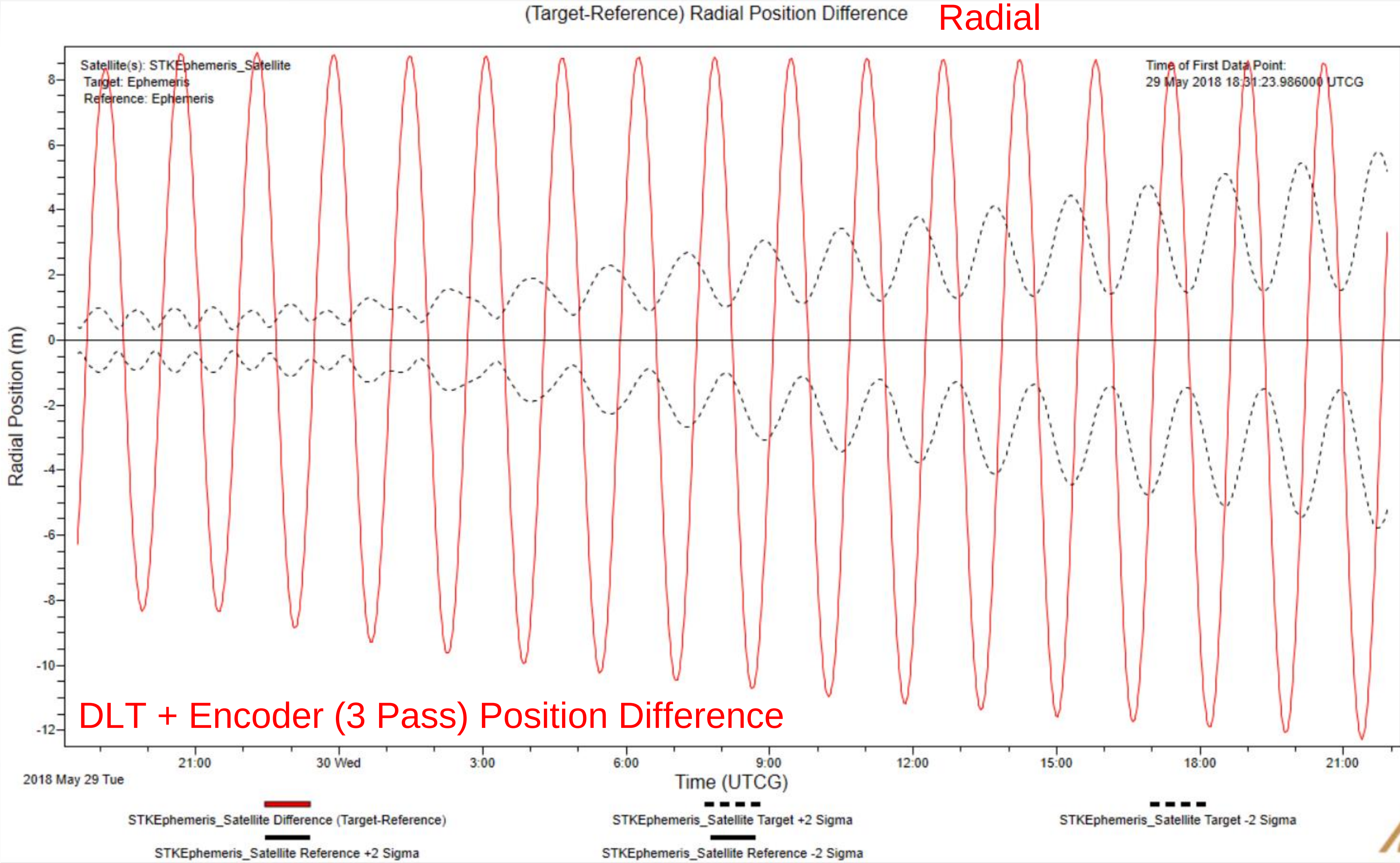
Result of OP Case 1-2



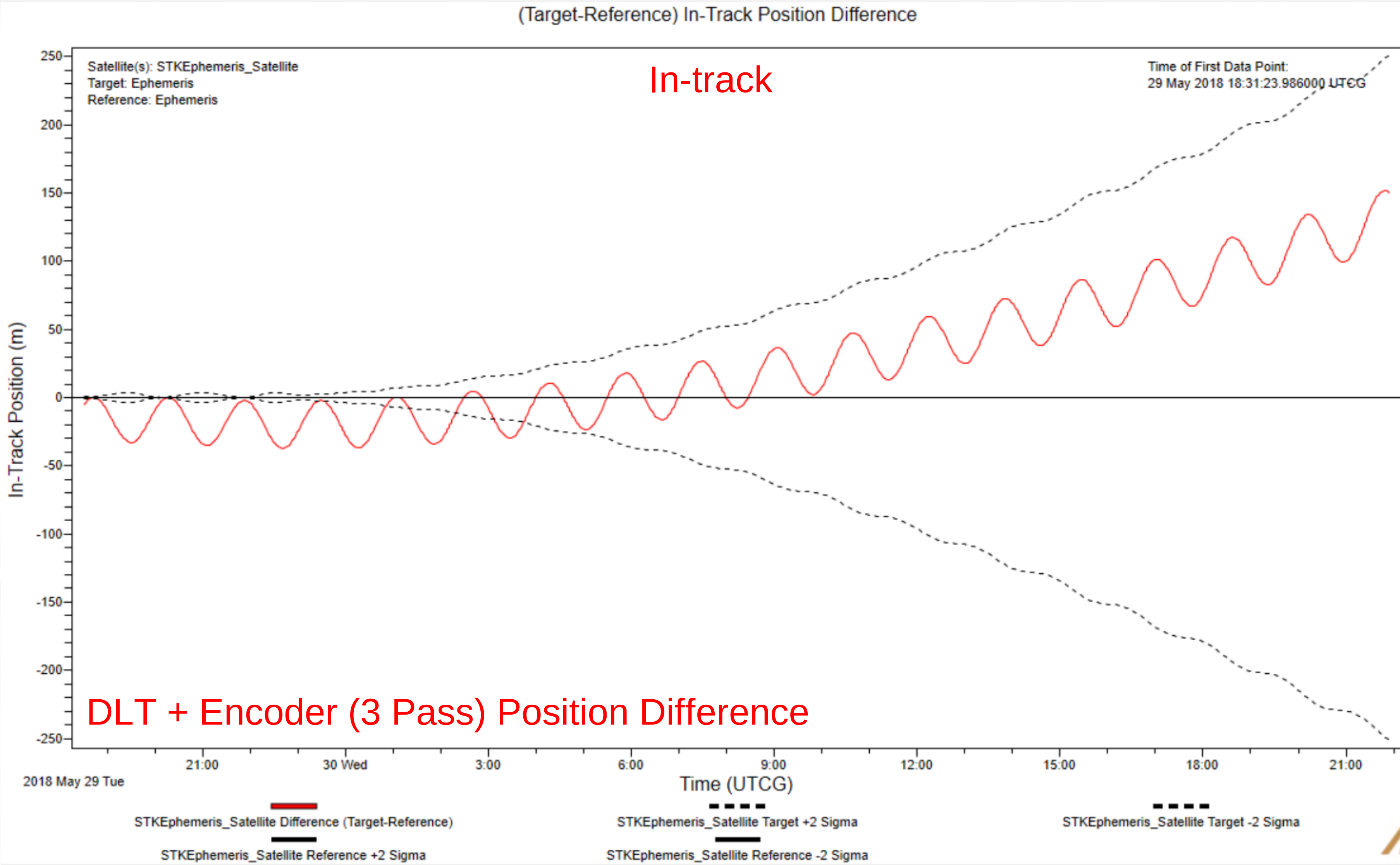
Result of OP Case 1-2



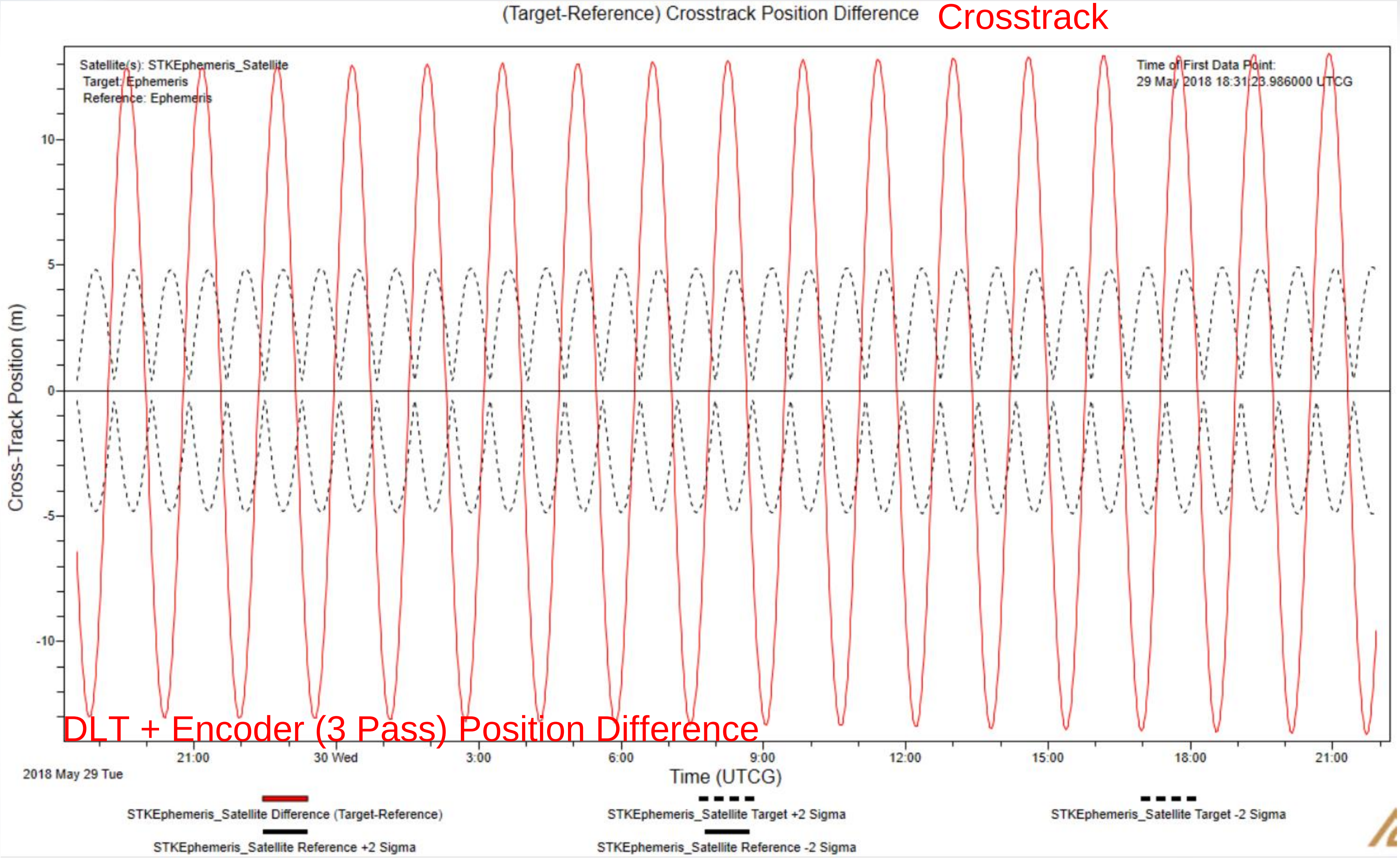
Result of OP Case 2-1



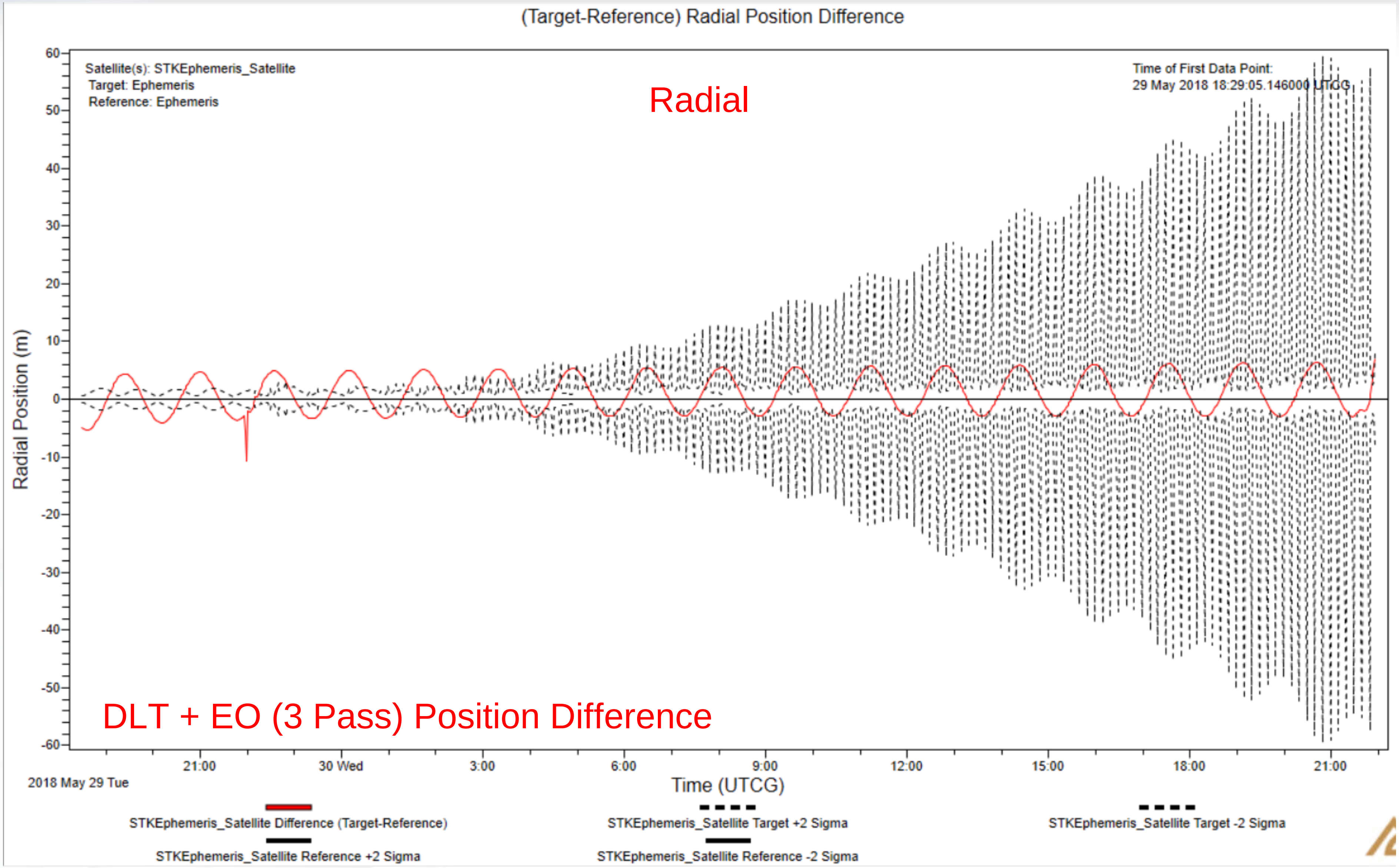
Result of OP Case 2-1



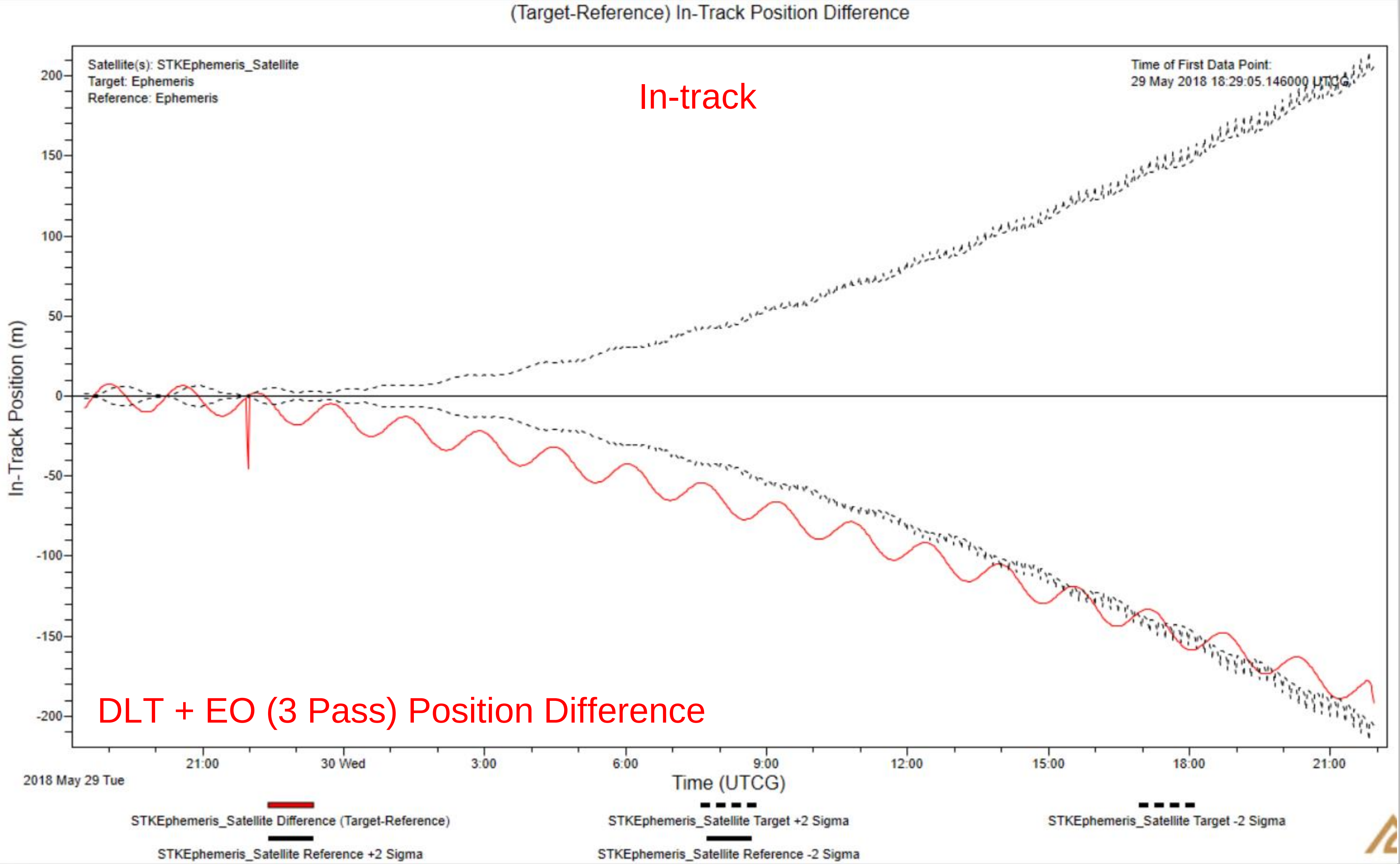
Result of OP Case 2-1



Result of OP Case 2-2



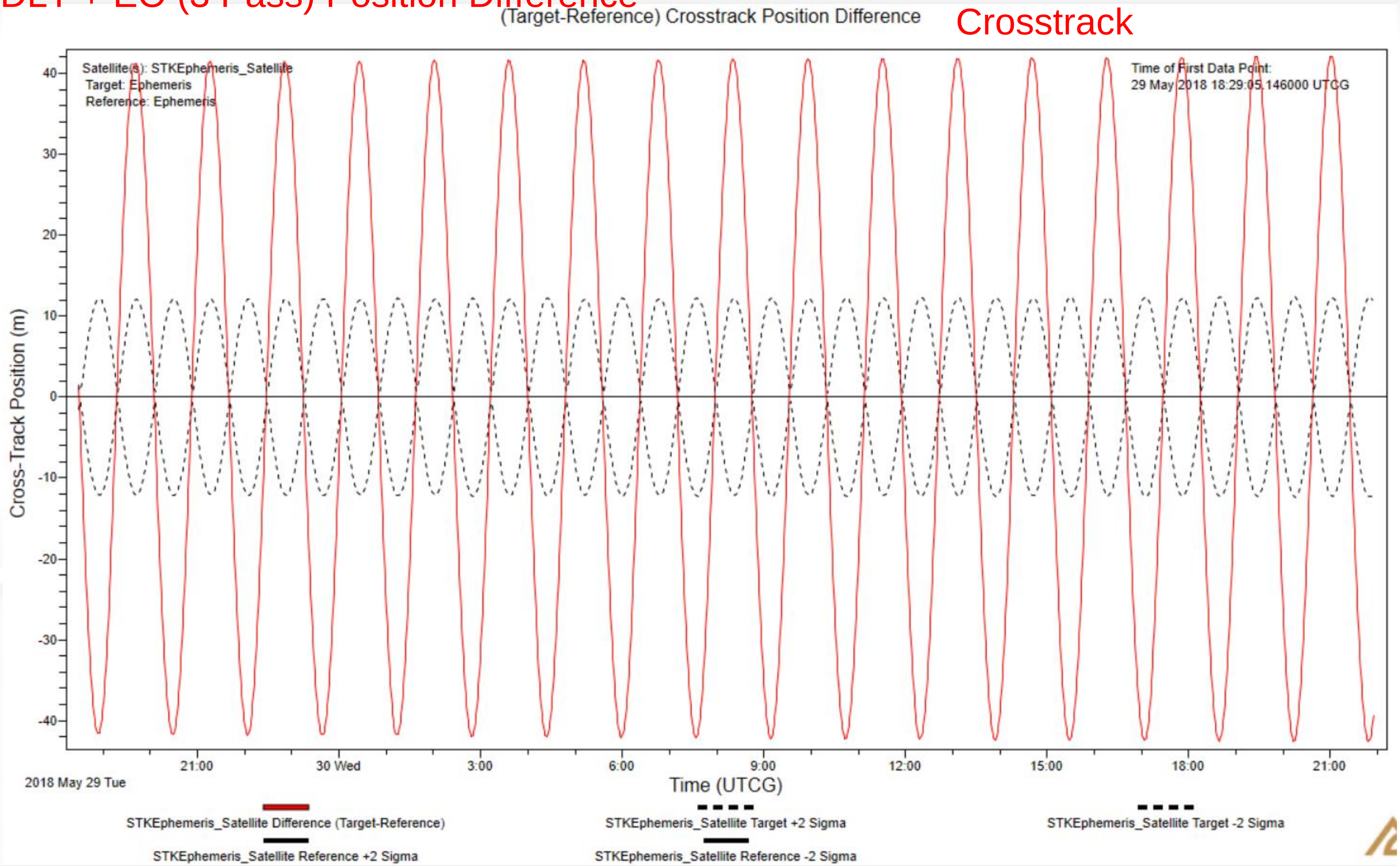
Result of OP Case 2-2



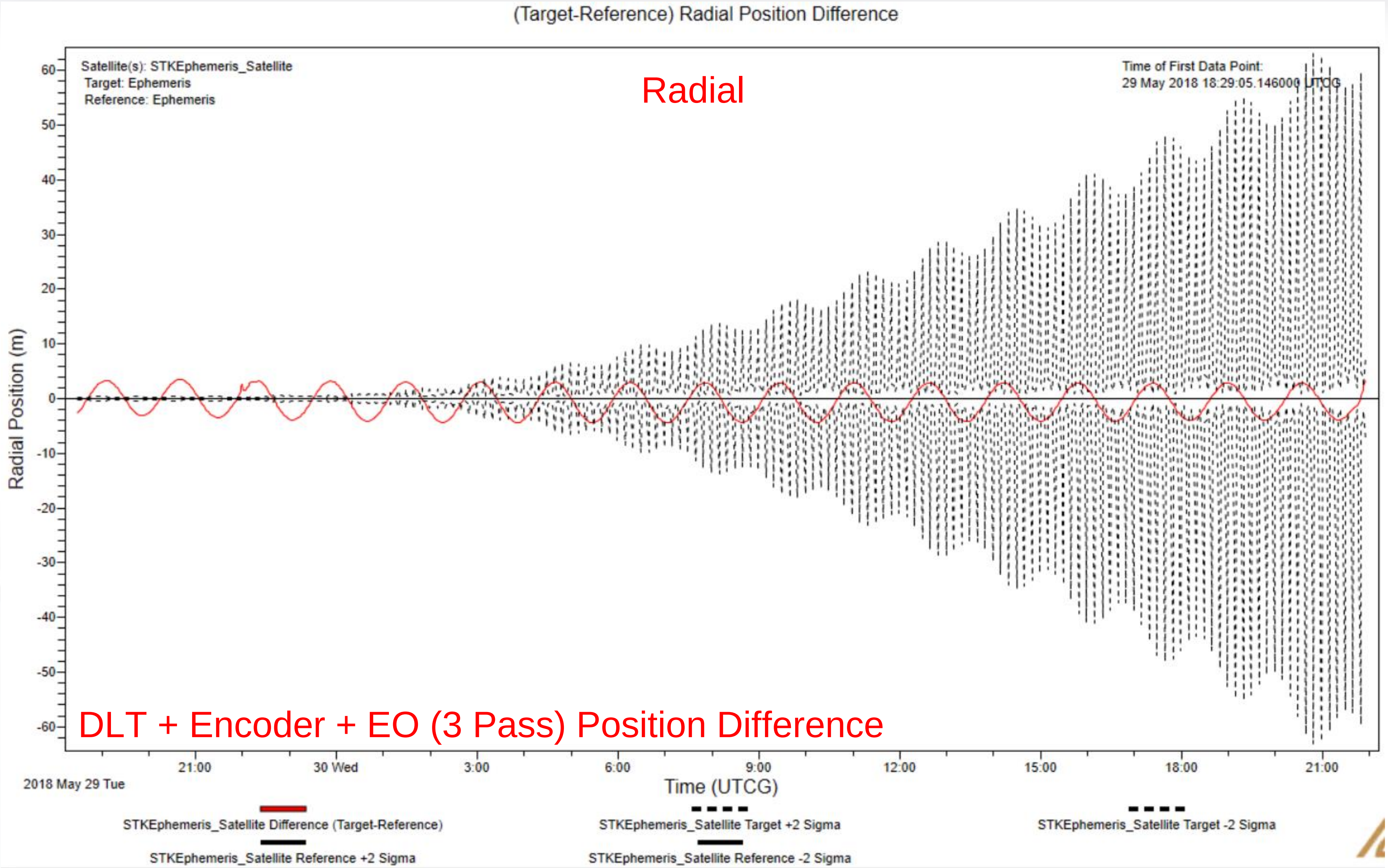
Result of OP Case 2-2

DLT + EO (3 Pass) Position Difference

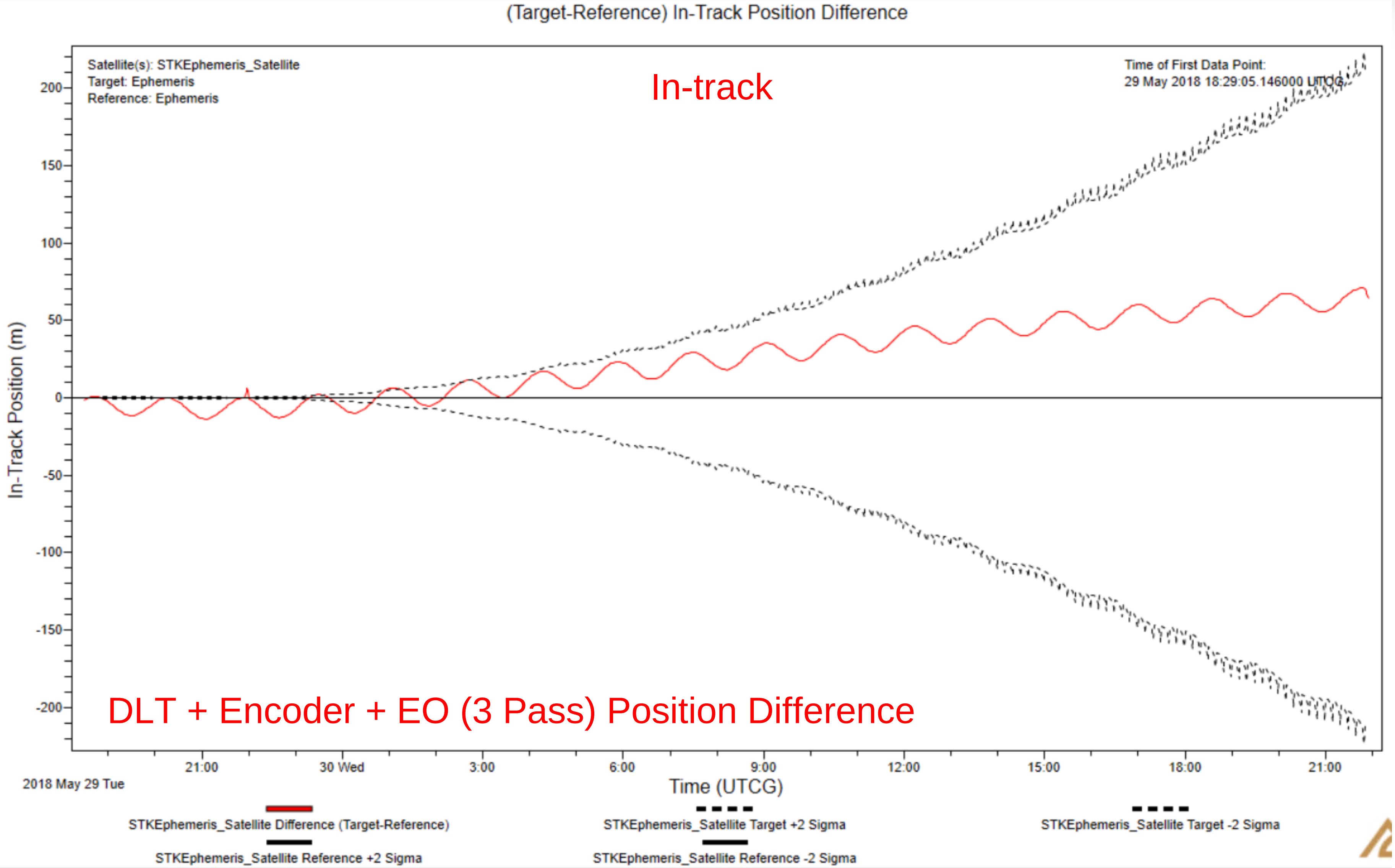
Crosstrack



Result of OP Case 2-3



Result of OP Case 2-3



Result of OP Case 2-3