# Commercial SSA Catalog Performance

**Robert Hall**
*Director, ComSpOC Operations*
*Analytical Graphics, Inc. (AGI)*
**Tom Johnson**
*VP of Engineering*
*Analytical Graphics, Inc. (AGI)*

**ABSTRACT**

***We present a summary over the last year of executing commercial SSA operations at AGI's Commercial Space Operations Center (ComSpOC) and examine some key performance statistics such as ephemeris accuracy, catalog completeness, and revisit rates, and maneuver detection and reconstruction performance.***

## 1. COMMERCIAL SPACE OPERATIONS CENTER

The Commercial Space Operations Center, or ComSpOC, is dedicated to the goal of detecting, tracking, characterizing and protecting all objects in space. ComSpOC leverages commercial SSA sensors that feed AGI’s SSA Software Suite. The SSA Software Suite (SSS) is AGI’s commercial solution for providing enterprise SSA in a scalable, reliable, and distributed service-oriented architecture (SOA) environment with a fully integrated database. SSS leverages industry proven and validated Orbit Determination Tool Kit, STK Components and STK to process the raw observation data and produce a catalog of SP-quality ephemerides. In the ComSpOC these system-produced ephemerides are referred to as HiDEph, for high-definition Ephemerides.

ComSpOC is able to easily scale up the core ComSpOC functions of Observation Ingestion and Association, Orbit Determination, Maneuver Processing, Propagation and Conjunction Assessment to hundreds of cores, using the SSS Mission Application Parallelization Service (MAPS). MAPS is a distributed processing framework that utilizes high performance commercial server hardware. Larger catalogs are supported by adding or allocating additional server hardware. No software modifications are required for this expansion.

ComSpOC distributes SSA products and services through its SpaceBook subscription service. SpaceBook provides access to subscribers of ComSpOC products and services on a Resident Space Object (RSO) basis. SpaceBook consists of a SOA to access data products as well as a browser based user interface providing subscription data and AGI’s Cesium visualization capability. The SOA can also be used by customers to automate publishing data to SpaceBook as well as retrieving finish products. Both SOAP and REST web API interfaces are supported.

The ComSpOC provides SSA products and services that support Safety of Flight, Mission Assurance and Space Traffic Management. The SSA products delivered in supporting these services include conjunction assessment screening, maneuver calibration and characterization, reentry analyses, rendezvous and proximity operations detection and monitoring. In addition to these SSA products, customers can also consume the HiDEph itself.

The ComSpOC collection, processing and distribution architecture is shown in Figure 1.

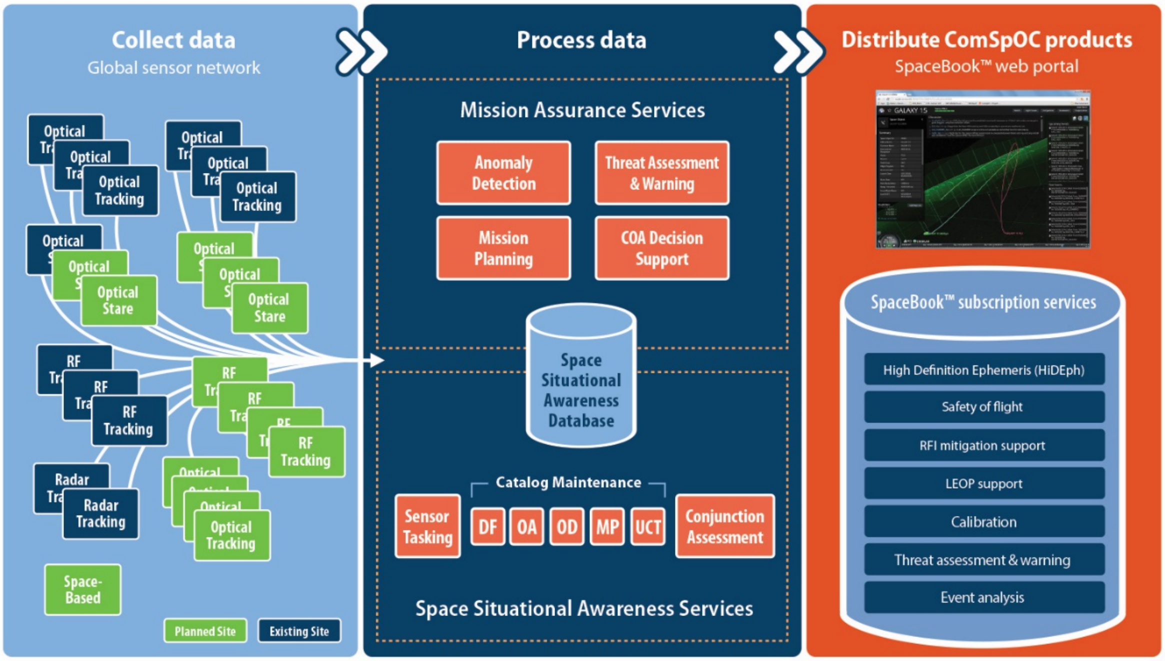


Fig. 1. ComSpOC Overview

## 2. COMSPOC SSA PROCESSING

With the commoditization of low-cost sensors, advanced image processing technology, the growing debris population, upcoming large LEO satellite constellations and the need to increase the fidelity and timeliness of SSA, the demand for commercial SSA services has grown. The key to the ComSpOC and its ability to rapidly process a scalable, highly accurate catalog is the SSA Software Suite processing layer. The SSS has at its core the same software 'engine' that is found in AGI's Orbit Determination Toolkit (ODTK). This tool encompasses an Extended Kalman Filter-based OD which provides realistic covariance, which is in turn critical for several downstream SSA analyses, including the proper assessment of true probability of collision for conjunctions.

Since the central software engine of the SSS is essentially the legacy commercial off-the-shelf ODTK engine, it is already able to fuse dozens of tracking data measurement types. This is critical in supporting an SSA system, facilitating the sensor network expansion and on-boarding to all types of sensors.

In addition to serving as the central engine of the OD process, these algorithms are also used for the Obs Association processing and they underpin the unique Maneuver Processing (MP) capabilities within the SSS. By virtue of this highly accurate and timely filter-based MP, maneuvers are automatically detected and processed, permitting continual track custody, and characterized to support pattern-of-life behavioral analyses.

The underlying system architecture used within the SSS results in a high degree of automation and notification requiring minimal operator innervation. It is architected as a fully scalable enterprise solution, using an Oracle database under the hood. The HiDEph that is produced by the OD and MP processes provides the necessary foundation for actionable conjunction assessment. Following the automated catalog processing consisting of Obs Association, Orbit Determination and Maneuver Processing, additional automated processes are executed which add an SSA analytical layer to the catalog. These includes reentry analysis, Geo Box Analysis, and rendezvous and proximity operations detection.

## 3. COMSPOC NETWORK

ComSpOC began operations in early 2014. Initially the network consisted of telescopes located around the globe for deep-space observations and radar for LEO observations. Since then, these have both expanded and the ComSpOC has added passive RF sensors to the overall network. Over time the entire operation has steadily grown. As the full build-out of the catalog occurs, the number and type of sensors and amount of time that sensors are providing are gated by present needs. Over the last few years all of these items have been increased. The amount of sensor operating time for existing sensors has been steadily increased, different sensor provider partners have expanded the size of their own networks, and ComSpOC has brought on more sensor provider partners. The result of this growth is depicted in figure 2, which shows the total number of daily observations for January – July of 2016. As can be seen toward the right hand side of the plot, in June and July we crossed over the one million obs per day threshold.

As part of the catalog processing, the ComSpOC orbit solutions are transmitted back to the sensor network for closed-loop tracking. This further enhances track custody, particularly in the presence of spacecraft maneuvers.

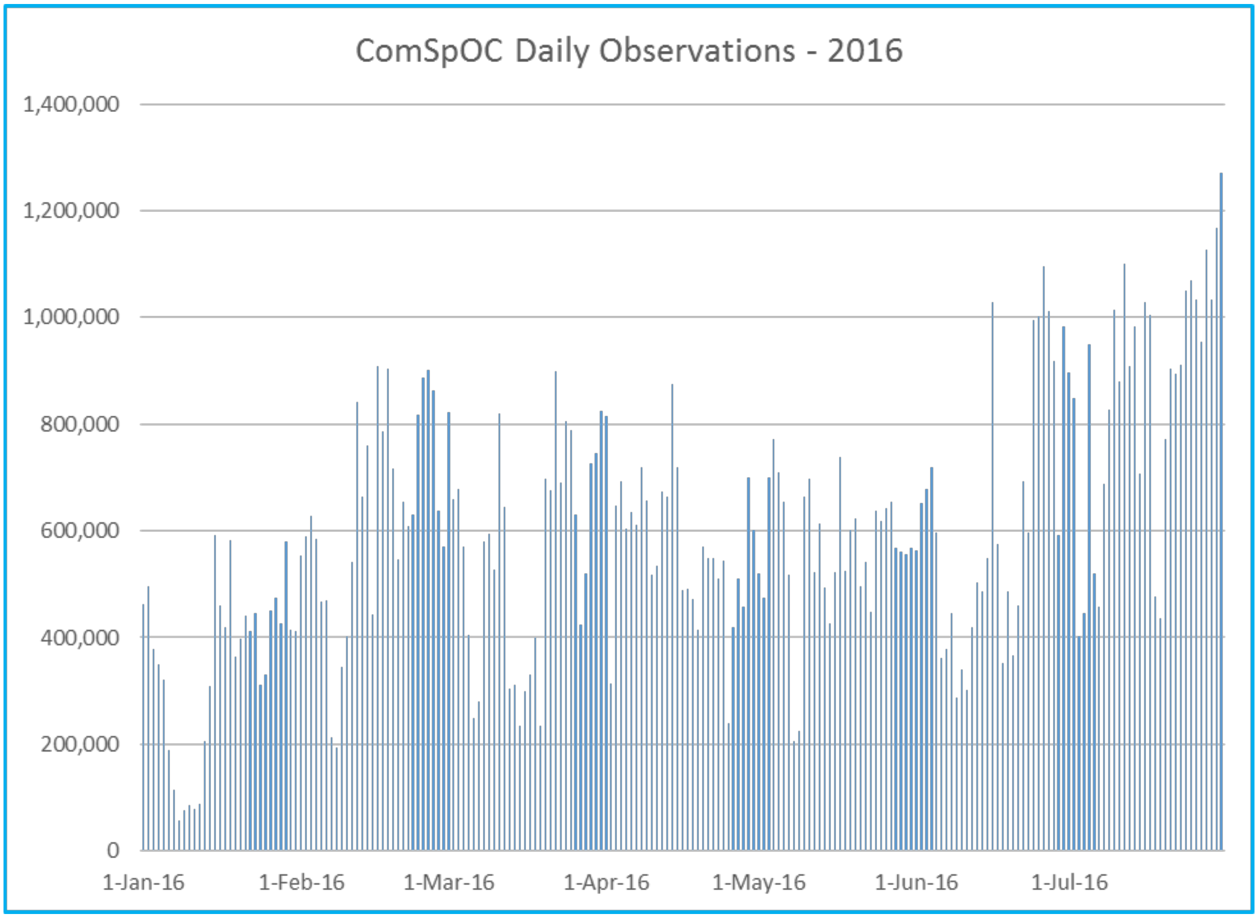


Fig. 2. ComSpOC Daily Observations Throughput - 2016

## 4. CATALOG COMPLETENESS

Since beginning operations, the ComSpOC catalog has continued to grow. With an early emphasis on optical sensors the GEO catalog has grown most rapidly, although other orbit regimes are growing as additional sensors have been added. Figure 3 shows the ComSpOC catalog as measured against the USAF public catalog on space-track.org for July 2016, broken down by orbit regime.

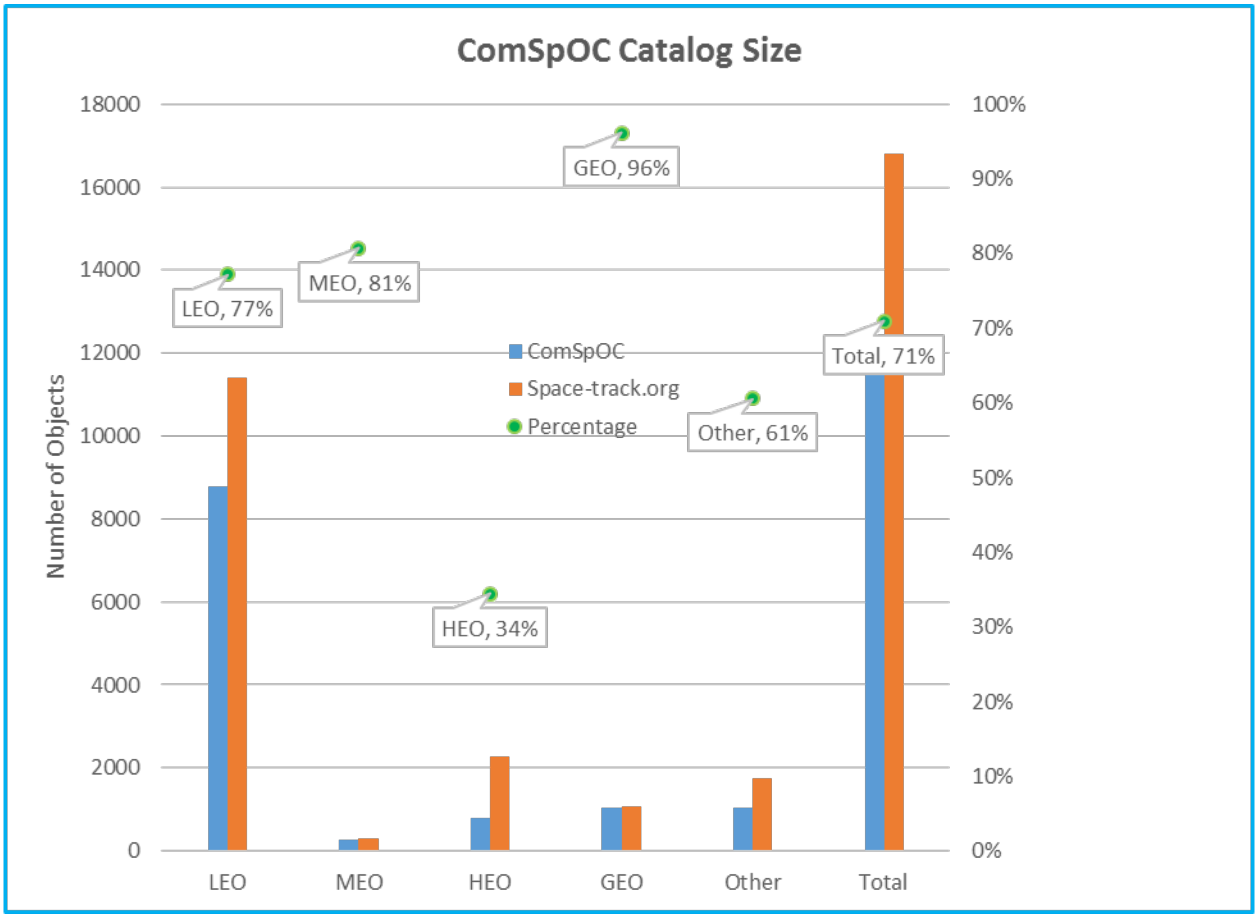


Fig. 3. ComSpOC Catalog Completeness – July 2016

In addition to tracking objects in the space-track.org catalog, ComSpOC maintains an analyst satellite catalog consisting of objects for which there are no TLEs published on space-track.org. These analyst satellites are used to permit enhanced safety of flight screening for customers. However, orbital data for these analyst satellites is not released to customers.

The ComSpOC roadmap includes the addition of several new sensors and sensor types. In order to meet the most stringent safety of flight needs, future plans are targeting a catalog that is an order of magnitude larger than the existing public catalog on space-track.org. Having such a catalog will also provide a much better foundation for overall SSA, in terms of monitoring the environment for threatening actors who would not otherwise be able to be pre-identified.

## 5. COMSPOC CATALOG TRACK DENSITY

The quantity and diversity of the ComSpOC sensor network permits frequent revisits. Besides simply adding to the number of sensors in ComSpOC, by employing a network consisting of several sensor providers, ComSpOC has redundancy and this helps mitigate potential systematic issues within a given sensor provider.

A greater emphasis is placed on tracking active satellites as compared to on-orbit debris. In this context, we do not differentiate within debris between retired or dead spacecraft, spent rocket bodies or true pieces of debris. The track density across various orbit regimes, separated into active and debris objects, is shown for the last three years in Figure 4. As can be seen, the track density continues to increase across all orbit regimes.

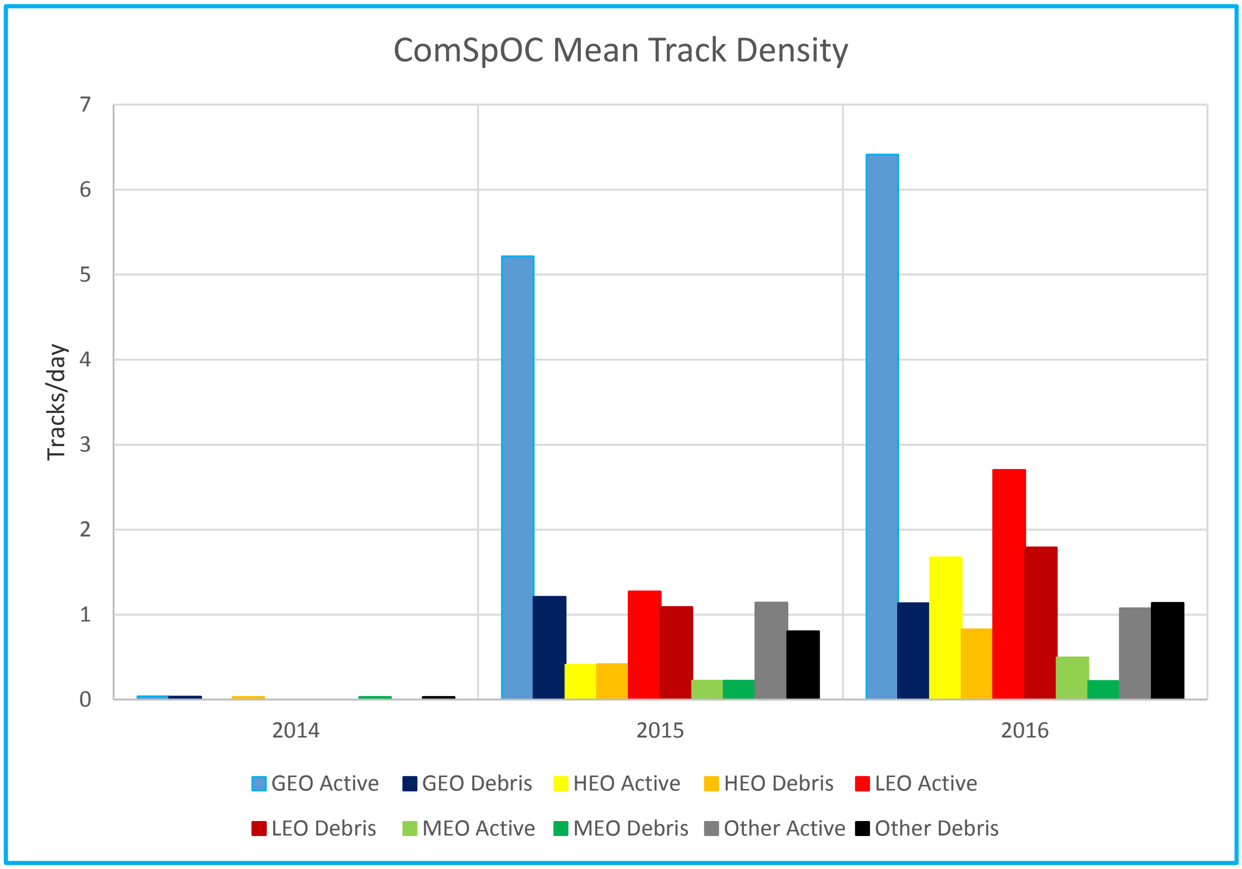


Fig. 4. ComSpOC Catalog Track Density

### 6. MANEUVER DETECTION & CHARTACTERIZATION

The ComSpOC automatically detects and characterizes approximately 1500 maneuvers per month. This processing permits full track custody, and the computed maneuver characterization data is the historical foundation for vehicle pattern-of-life analysis, which can be used to rapidly assess whether newly detected maneuvers are ‘in family’ or not. This, combined with additional processing tools to evaluate an objects orbit in the context of its history, provide layers of assessment that help identify unusual and potentially threatening behaviors. The number of maneuvers detected daily during 2016 is shown in Figure 5.

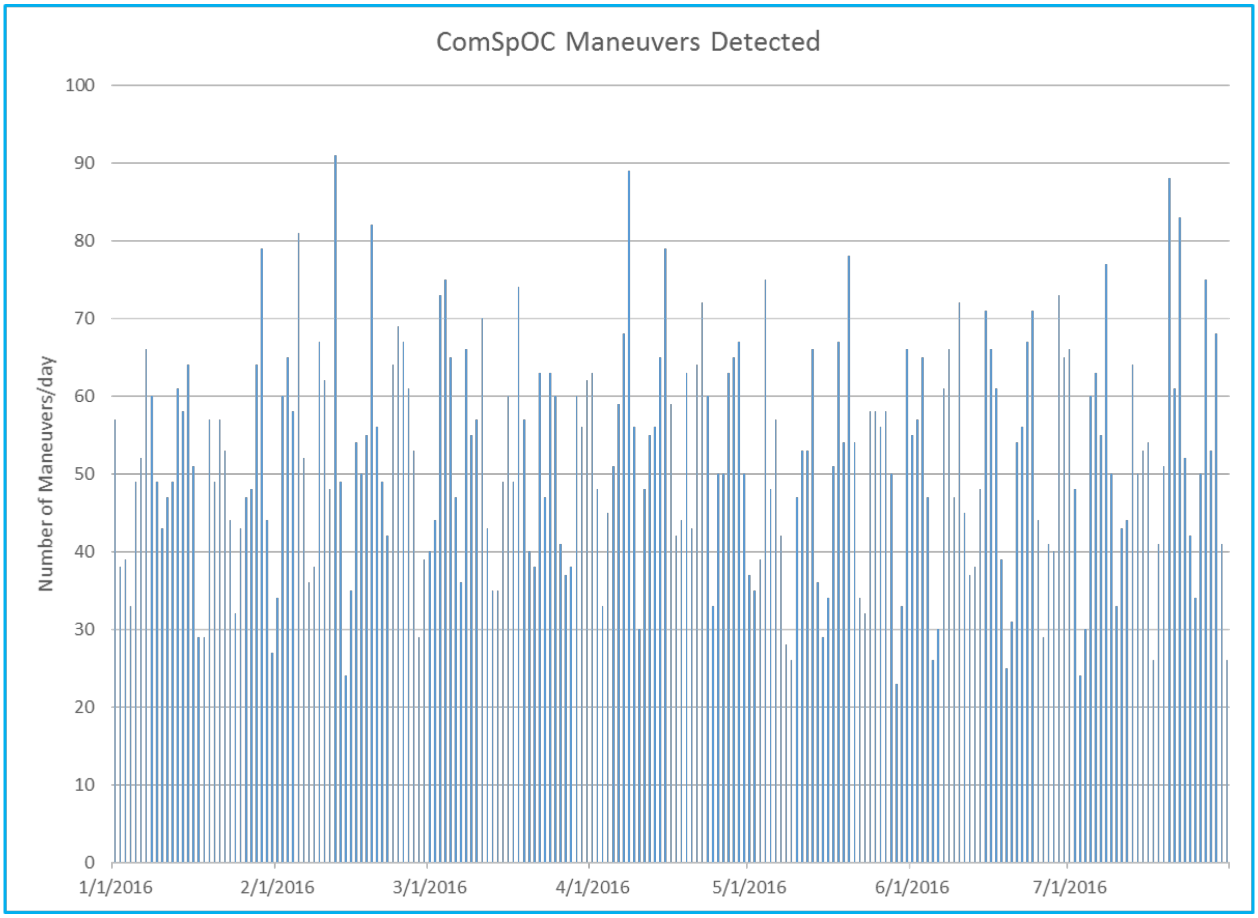

Fig. 5. ComSpOC Daily Maneuver Detections - 2016

## 7. ORBIT ACCURACY

The solutions computed within the ComSpOC are regularly checked. For all objects, a wide range of parameters are used to help compute an overall confidence metric. For several reference objects, orbital truth data is available, and these are routinely checked as part of assessing catalog health. Even though truth data is only available for a small fraction of the catalog, we know that the same sensor network and the same SSA Software Suite algorithms are being used holistically for the catalog, which means that we can assess the accuracy of the reference satellites as a proxy for the entire catalog. In the ComSpOC we measure the instantaneous distance between the truth solution and the ComSpOC HiDEph.

In LEO, there are several Satellite Laser Ranging (SLR) reference satellites. For these objects, SLR measurements are available which can be used to construct an orbit accurate to centimeters. The orbit accuracy comparison for two of hese objects, LARES (38077) and LARETS (27944), are shown in Figures 6 and 7, respectively. These figures demonstrate that for LEO the HiDEph solution is good to within 100 meters.

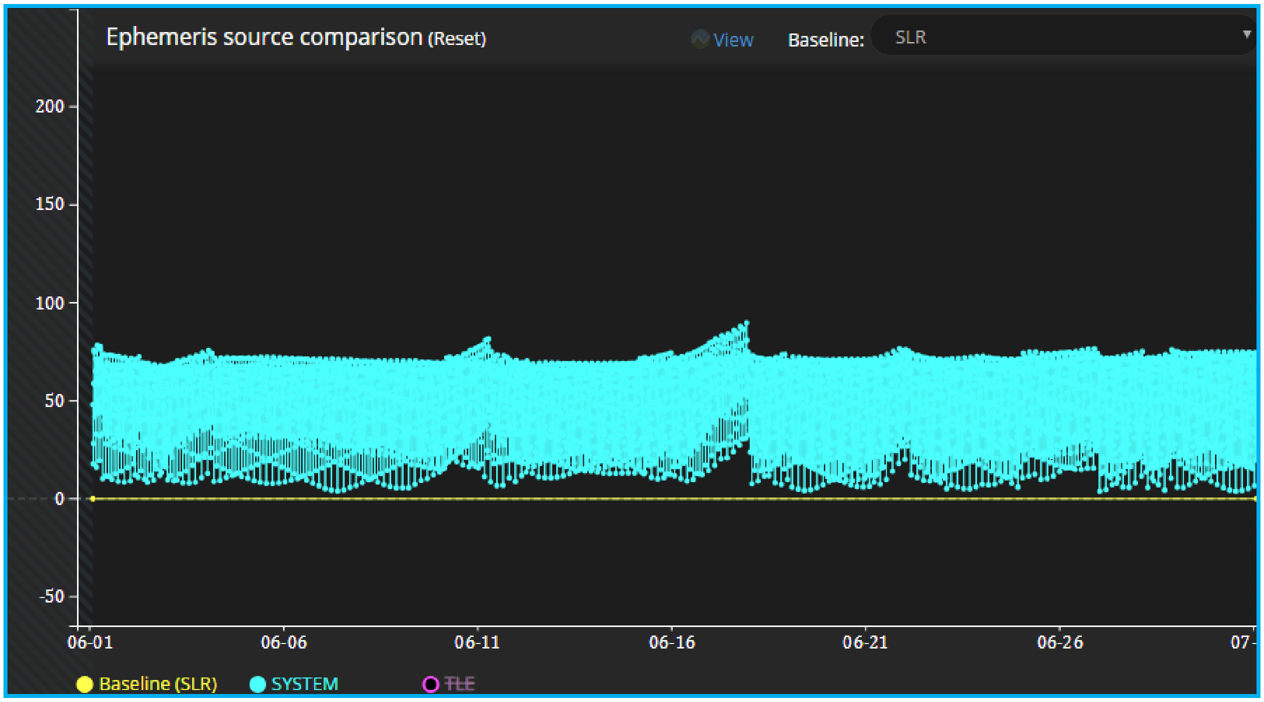


Figure 6. LARES Orbit Accuracy

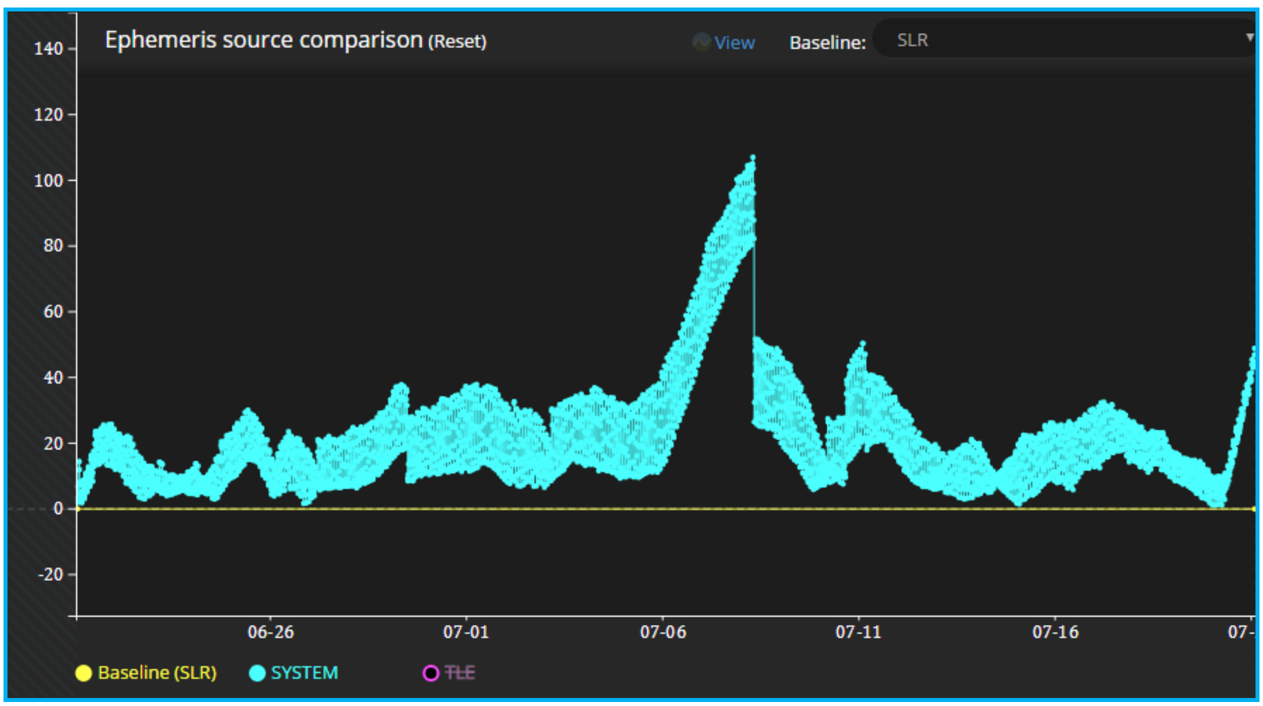


Figure 7. LARETS Orbit Accuracy

For GEO, there are at least 5 different systems used which provide truth data for the spacecraft in question. There systems are noted in Table 1.

| GEO Reference Sats | | |
|---|---|---|
| WAAS – Wide-Are Surveillance System | North America | Galaxy 15<br>Inmarsat 4-F3<br>Anik F1R |
| GAGAN – GPS-Aided GEO Augmented Navigation | India | GSAT-8<br>GSAT-10<br>GSAT-15 |
| MSAS – MTSAT Satellite Augmentation System | Japan | MTSAT-2 (Himawari-7) |
| QZSS – Quasi-Zenith Satellite System | Japan | QZS-1 |
| Beidou | China | Beidou G1, G3, G4, G5, G6, G7<br>Beidou IGSO 1, 2, 3, 4, 5, 6 |

Table 1. GEO Reference Satellites

Data for Galaxy-15 (28884) is shown in Figure 8. Appendix A contains similar data for several additional GEO reference satellites. Collectively, these data demonstrate that the ComSpOC ephemeris at GEO is typically accurate to approximately 200 meters. Producing orbits with errors this small is critical to providing accurate safety of flight warnings.

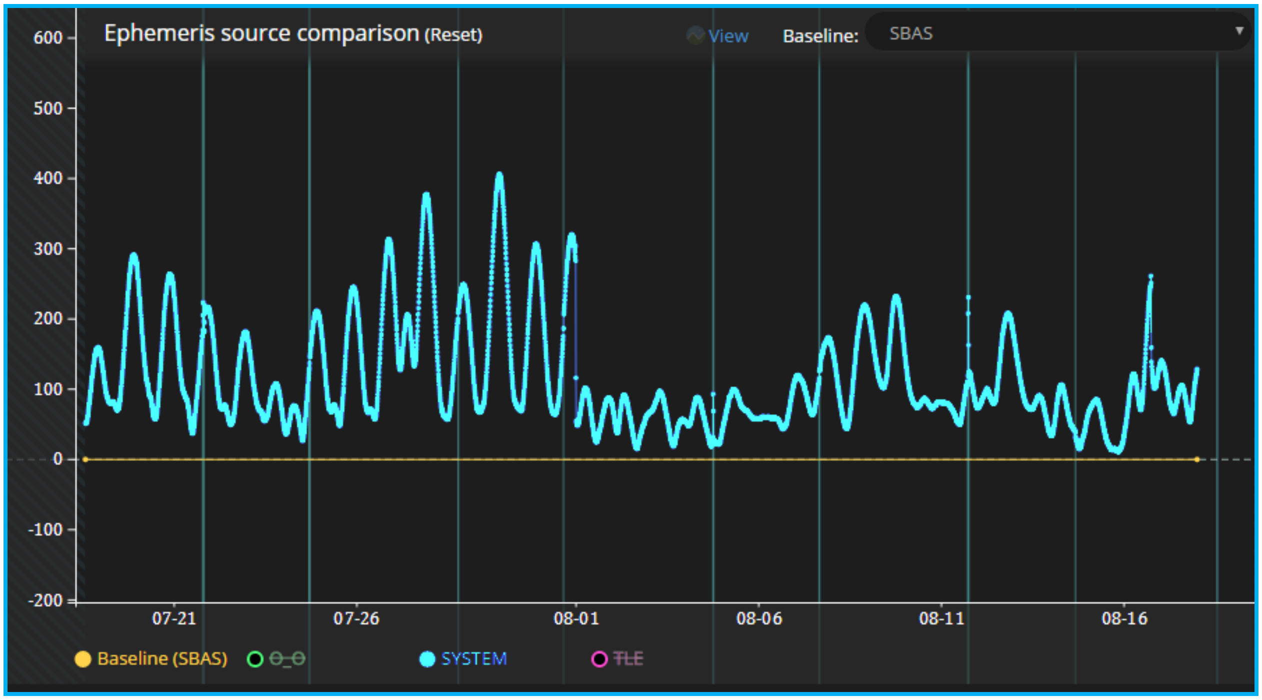


Figure 8. Galaxy 15 Orbit Accuracy

## 8. SUMMARY

The ComSpOC catalog continues to grow, as it approaches the scale of the USAF public catalog. The GEO portion of the ComSpOC catalog is nearly complete at this time. At the same time, ComSpOC has begun maintaining a separate analyst catalog of additional objects. Going forward, the sensor network is continuing to grow in both sensor numbers and sensor types, which will ensure that the catalog continues to grow.

Over the last few years ComSpOC has demonstrated the ability to produce SP-quality ephemerides, maneuver characterization information and conjunction screening on a full catalog of thousands of objects. As evidenced by the reference satellite population, ComSpOC has demonstrated orbit accuracies of 100-200m from truth.

The ability to produce and maintain a comprehensive catalog in a timely manner with such accuracies serves as the foundation for true space situational awareness.

## A. GEO ORBIT ACCURACY RESULTS

Included herein, in Figure A-1 through A-12, are additional GEO reference satellite orbit accuracy plots.

The following satellites are included, listed in order of longitude from west to east.

| Figure | Name | SSC | Longitude |
|---|---|---|---|
| A-1 | Anik F1R | 28868 | -107.3 |
| A-2 | Inmarsat 4-F3 | 33278 | -98 |
| A-3 | Beidou G5 | 38091 | 59 |
| A-4 | GSAT-10 | 38779 | 83 |
| A-5 | Beidou G6 | 38953 | 84 |
| A-6 | Beidou IGSO 5 | 37948 | 95 |
| A-7 | Beidou G3 | 36590 | 110.5 |
| A-8 | Beidou IGSO 2 | 37256 | 120 |
| A-9 | QZS-1 | 37158 | 138 |
| A-10 | Beidou G1 | 36287 | 140 |
| A-11 | Himawari-7 | 28937 | 145 |
| A-12 | Beidou G4 | 37210 | 160 |

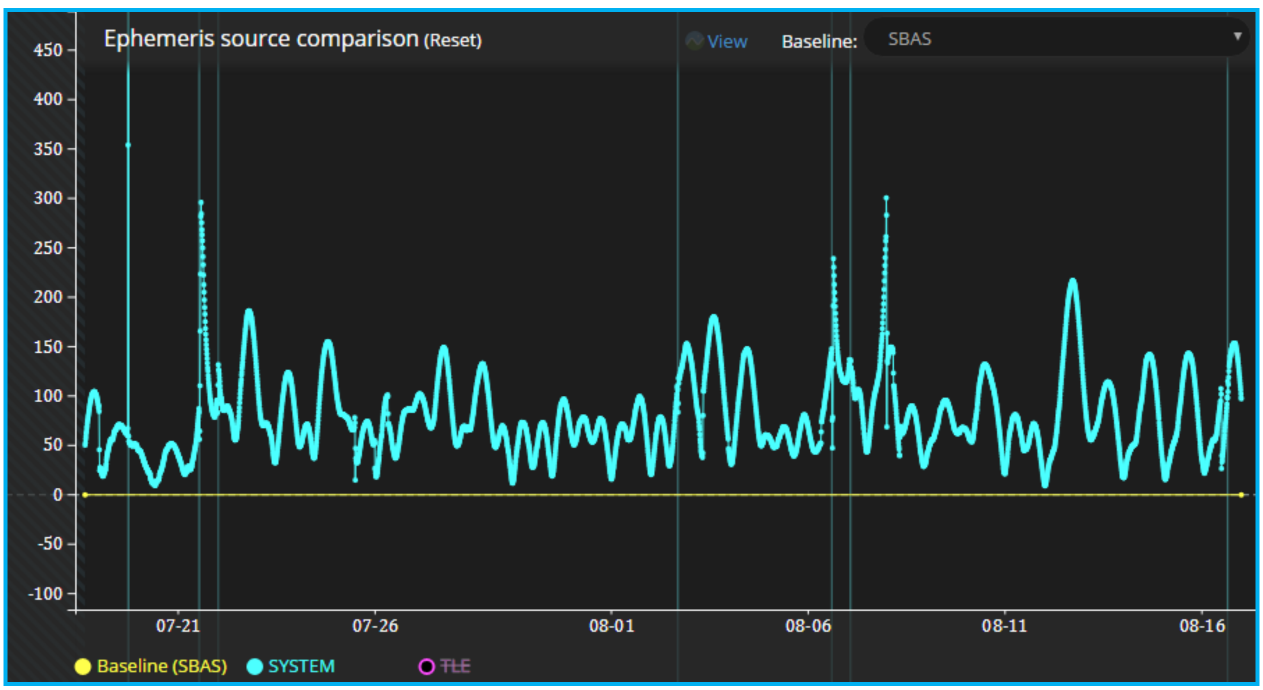


Figure A-1. Anik F1R Orbit Accuracy

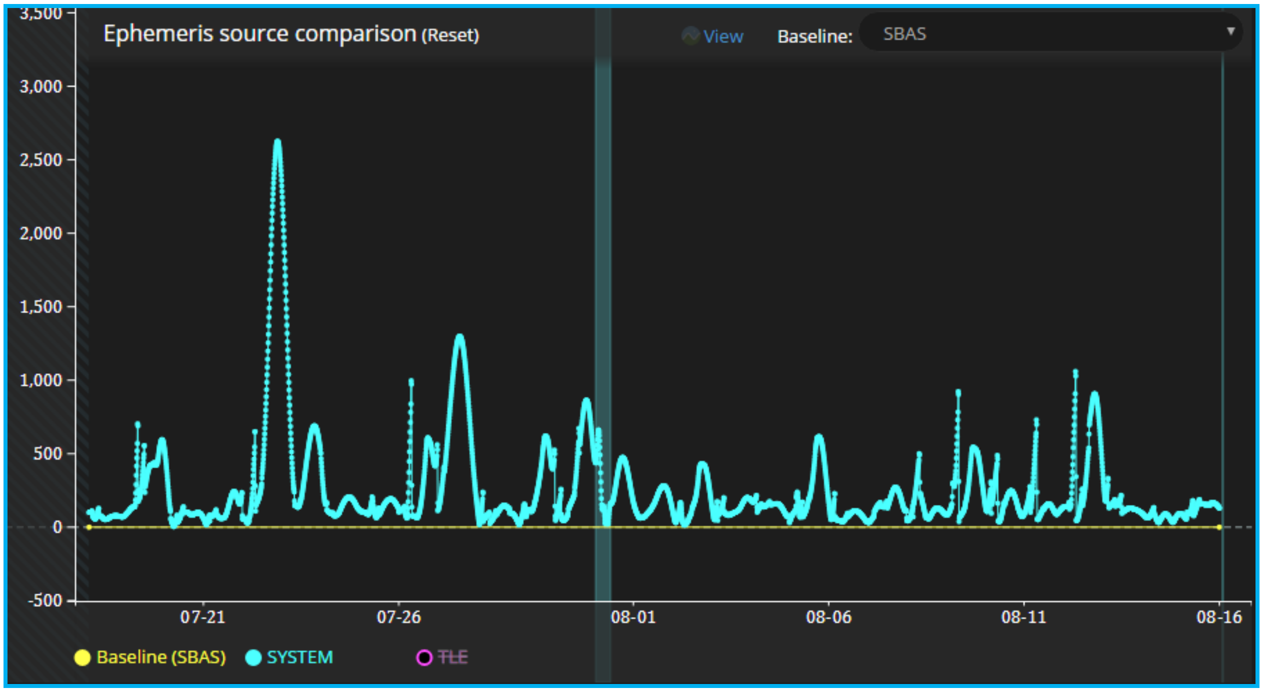

Figure A-2 Inmarsat 4-F3 Orbit Accuracy

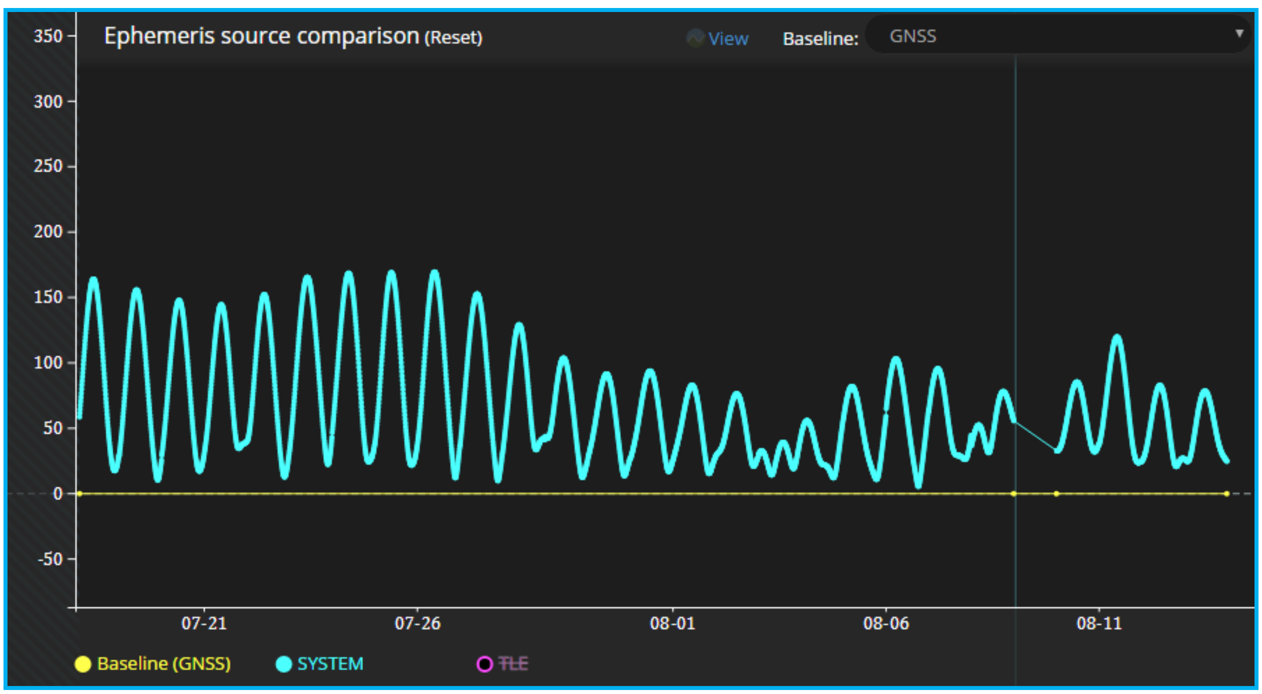

Figure A-3. Beidou G5 Orbit Accuracy


Figure A-4. GSAT-10 Orbit Accuracy

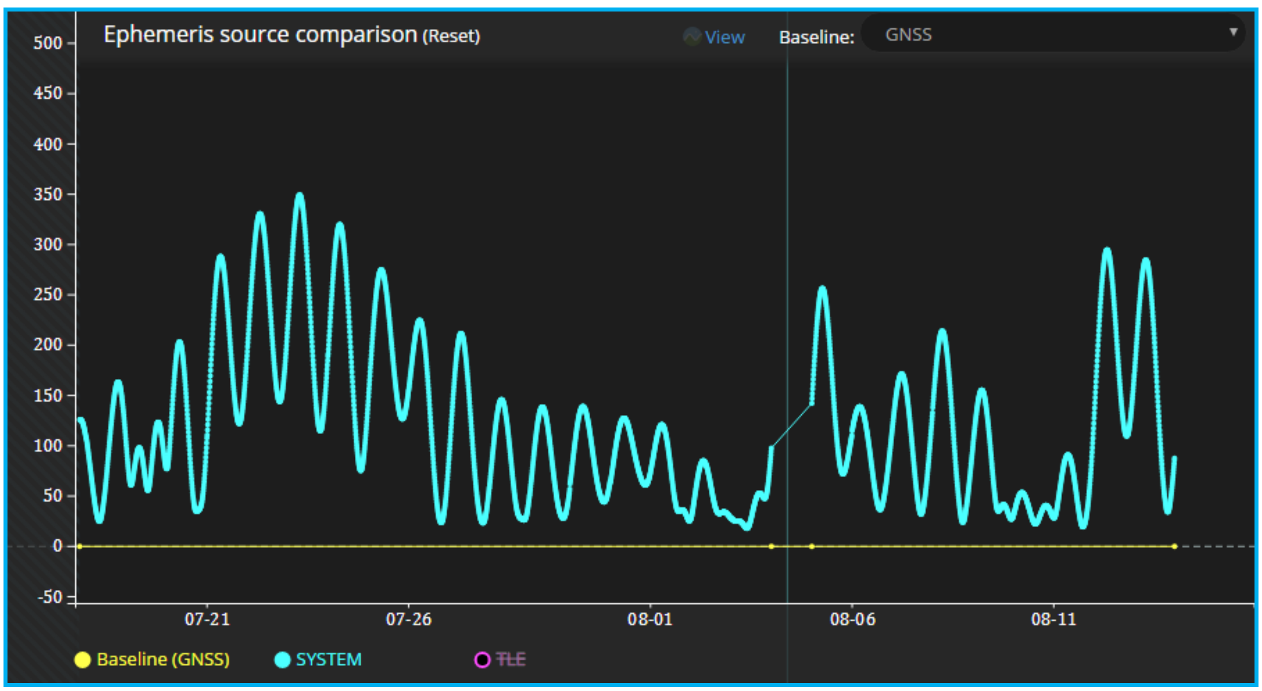


Figure A-5. Beidou G6 Orbit Accuracy

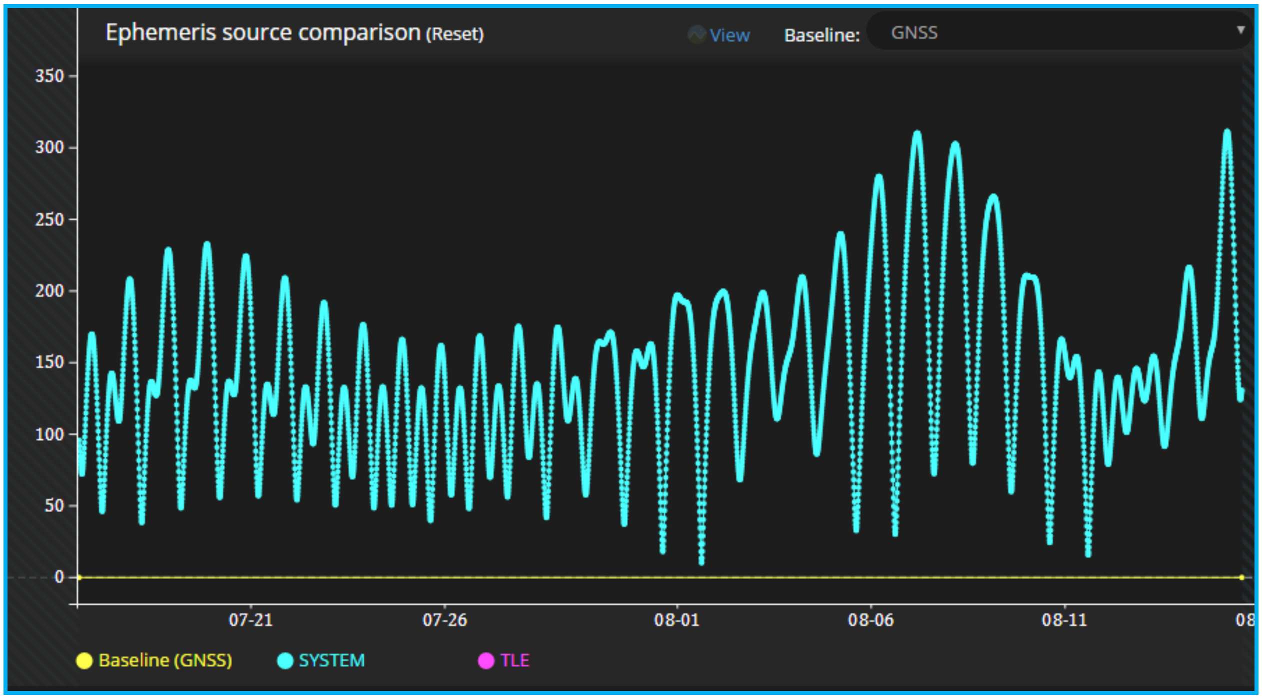

Figure A-6. Beidou IGSO 5 Orbit Accuracy

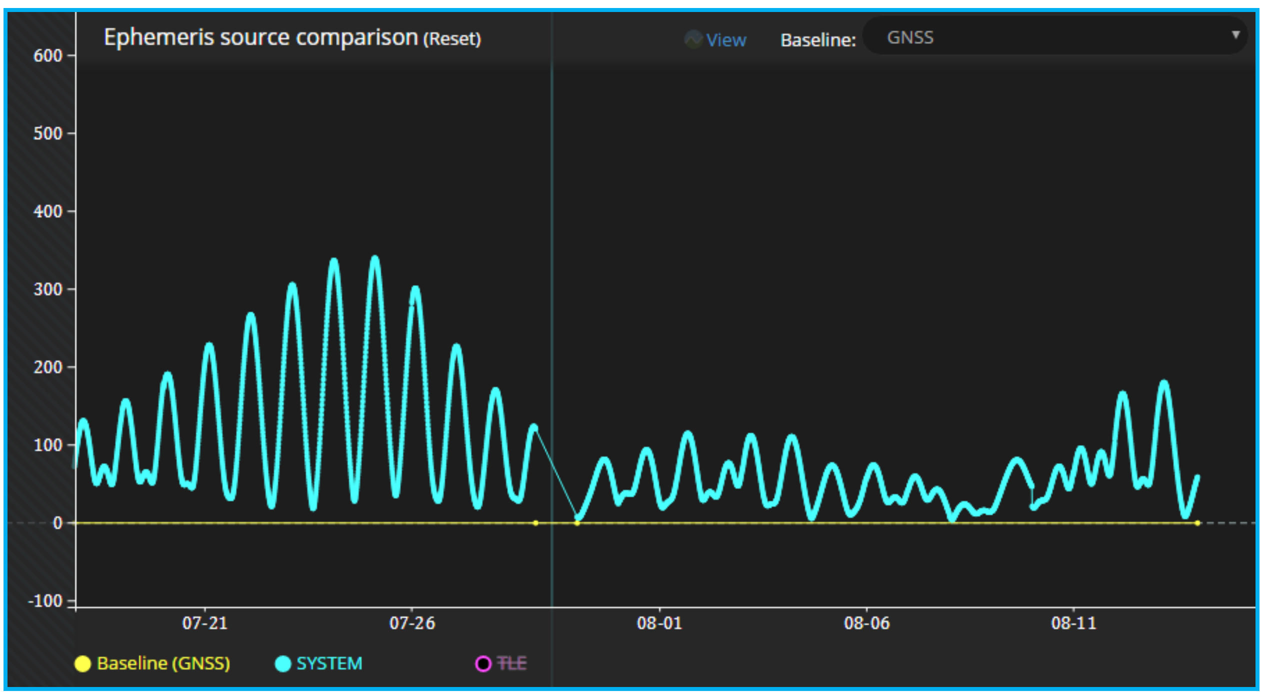

Figure A-7. Beidou G3 Orbit Accuracy


Figure A-8. Beidou IGSO 2 Orbit Accuracy

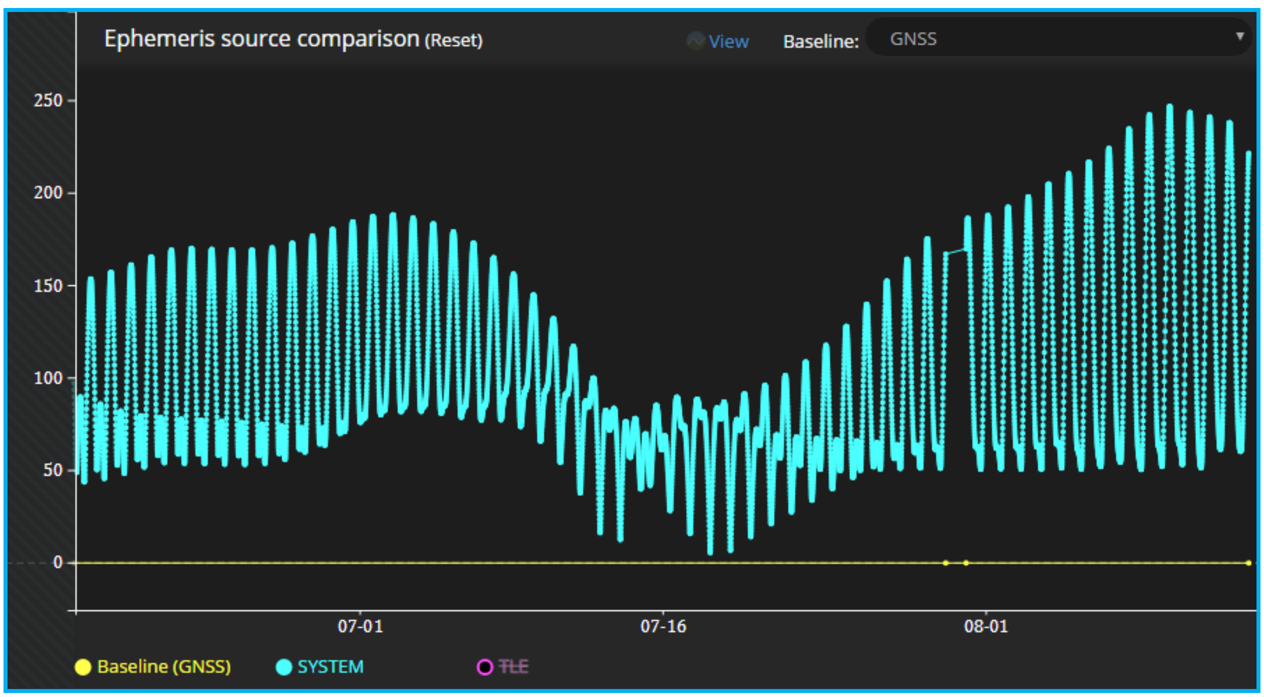


Figure A-9. QZS-1 Orbit Accuracy

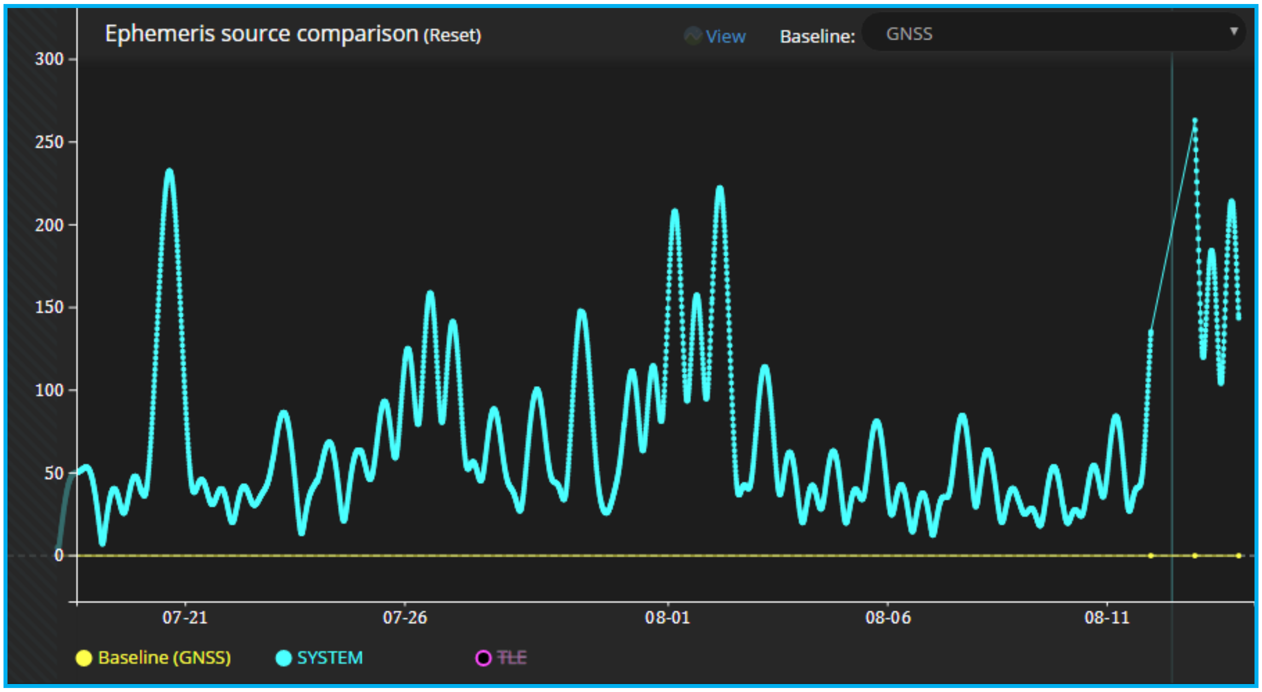

Figure A-10. Beidou G1 Orbit Accuracy

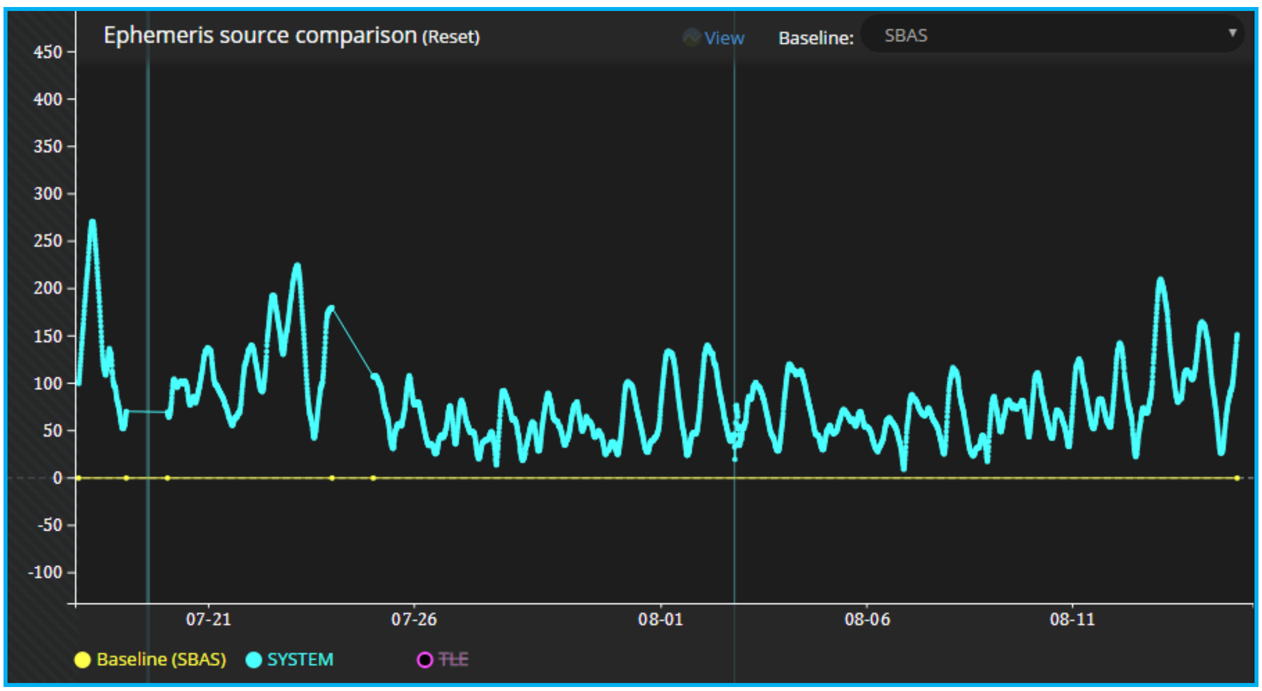

Figure A-11. Himawari-7 Orbit Accuracy

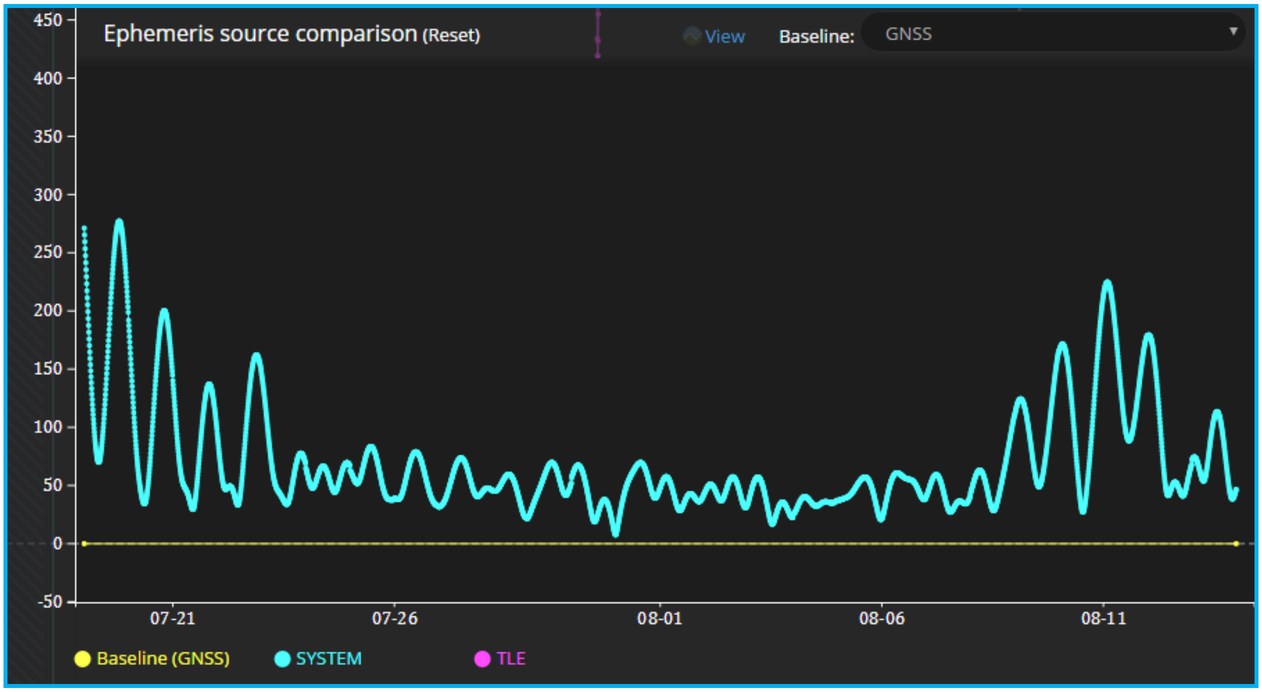


Figure A-12. Beidou G4 Orbit Accuracy

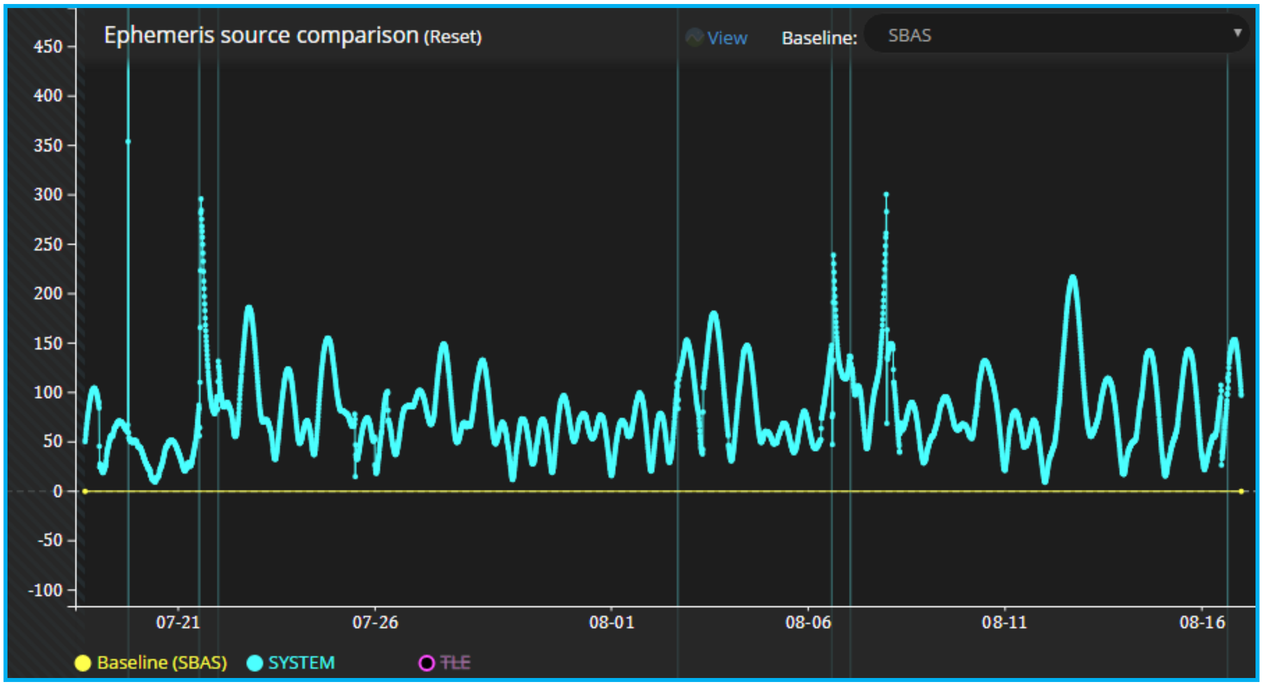


Figure A-1. Anik F1R Orbit Accuracy

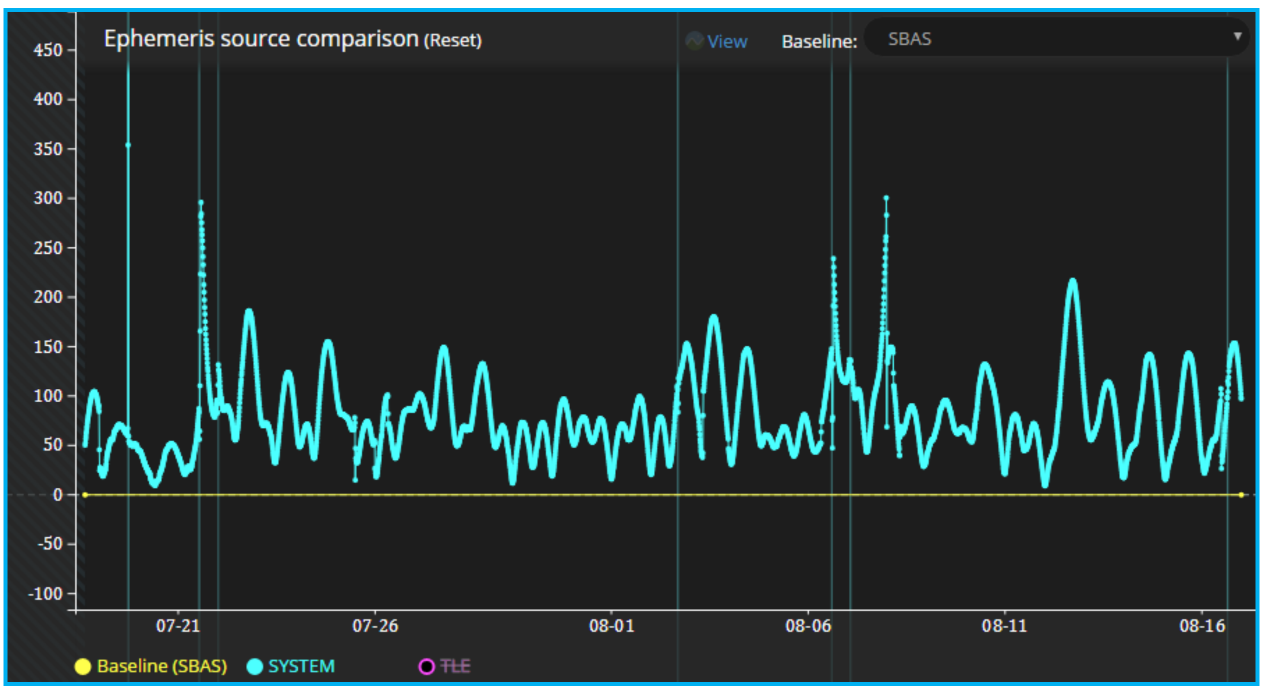


Figure A-1. Anik F1R Orbit Accuracy