ACCURACY ANALYSIS OF DIFFERENT ORBIT CATALOGUES THROUGH CALIBRATED OPTICAL OBSERVATIONS IN LEO

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ABSTRACT

Traditionally, different catalogues (TLEs, SP, CPF) have been used as reference for orbit propagation and observational ephemerides generation, to which different degrees of accuracy and reliability have been attributed.

This study aims, through the use of an optical sensor undergone iterative calibration adjustments, for the acquisition of an aleatory sample of objects measurements in LEO regimes, and the comparison and analysis with the positions generated from the different catalogues. Due to a fine calibration of the telescope sensor, observed positions are considered the ground truth, and discrepancies affecting the propagated orbits are shown and discussed for the different catalogues and the orbital characteristics.

Keywords:

1 INTRODUCTION

The availability of accurate and reliable reference ephemeris of the space objects population is of paramount importance for space surveillance activities, such as sensor pointing for tracking purposes or collision avoidance.

Observational ephemerides generation for sensor pointing is commonly performed using the TLE catalogue.

TLEs are known to have modest accuracy [1], but they are commonly in use since they are a free and publicly available source of orbital elements. While usually the accuracy they provide is enough to include the tracked object inside the field of view, TLEs may be not sufficiently reliable for some other more stringent requirements techniques as for photometric tracking and characterization.

Besides the TLE catalogue, in the last few years the SP (special perturbations) catalogue has become available. It is known to be more reliable than TLEs, as it uses a more accurate propagation theory. It is maintained by the 18 Space Defence Squadron and provided upon agreement [2].

CPF (Consolidated Prediction Format) orbits are available for objects tracked by the International Laser Ranging Service (ILRS) [3]. These orbits are extremely accurate and can be used as a reference for sensor calibration.

For this study, observations acquired by using the Antsy 2 optical telescope [4], part of Deimos Sky Survey (DESS) observatory, have been used to calibrate the sensor by using precise CPF orbits as ground truth.

The errors on Antsy 2 observations have been shown to regularly be below 3 arcsec when performing such calibration on ILRS targets, thus the observations themselves can be successively used as ground truth to assess the accuracy of a-priori orbits of other observed objects.

An aleatory sample of LEO objects crossing the sky during three nights has been tracked and the obtained measurements were compared respectively with the latest available SP and TLE orbits for each object, to provide an estimate of the deviations of these catalogues.

2 DEIMOS SKY SURVEY (DESS) OBSERVATORY

DESS is an observatory facility located in a natural park on Niefla mountains (Ciudad Real, Spain), with very good observation conditions and low light pollution. It comprises 4 telescopes, routinely performing observations in both survey and tracking mode and in the GEO, MEO and LEO orbital regimes.

As the relative object velocity increases in LEO, more stringent requirements must be fulfilled. LEO observations have some critical aspects to be taken into account on the sensors performance, for example, mounts shall be fast enough with very accurate timestamps below 1 millisecond.

3 CALIBRATION

The calibration procedure is performed by using CPF orbits as the ground truth for comparison with the acquired measurements. Two objects have been considered for the calibration process for this study, STARLETTE (Cospar ID: 75010A) and STELLA (Cospar ID: 93061B) satellites.

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Ed. T. Flohrer, R. Moissl, F. Schmitz (http://conference.sdo.esoc.esa.int, February 2023)

Measurements deviations from the reference orbit are computed in the along-track, cross track and radial (ACR) frame, as well as in terms of Right Ascension and Declination.

In addition to the standard calibration process, for this study an analogous procedure has been performed also with the latest available SP ad TLE orbits for the same objects.

4 CALIBRATION RESULTS

4.1 Starlette

The following figures show the results obtained for the calibration performed with Starlette. Figure 1 shows the errors of the observations with respect to the CPF orbit in the ACR frame.

As it can be seen, all three components are centred around zero with gaussian error that does not show any path. The along track error component is similar to the cross-track. This shows that the time synchronization and its dispersion uncertainty, has not introduced additional noise in the along-track and it is similar to the contribution of the error given by the object centroid individuation in the images.

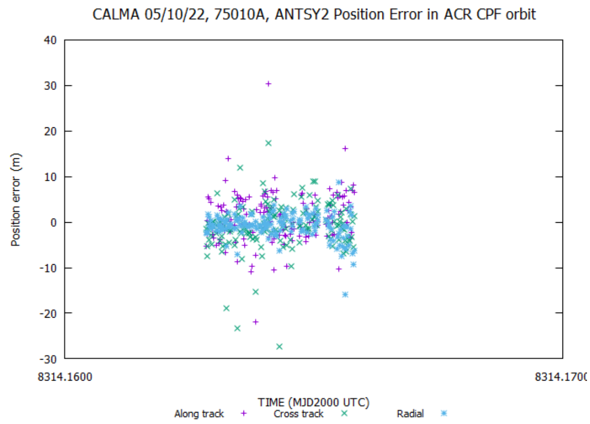

Figure 1. Calibration results in ACR frame for Starlette satellite against CPF reference

Figure 2 shows the results in terms of Right Ascension and Declination. Most of the points are below 1 arcsec, and the distribution of errors does not show significant trends.

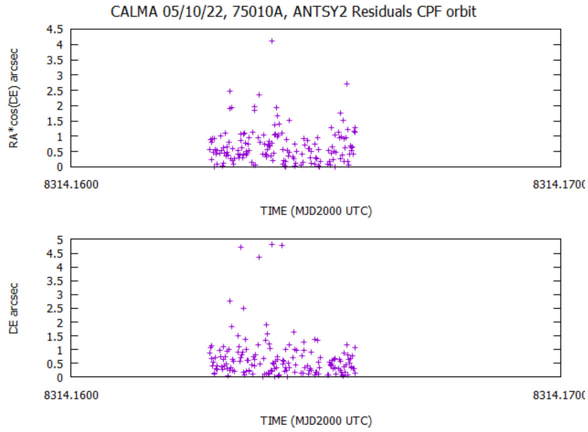

Figure 2. Calibration results in Right Ascension and Declination for Starlette satellite against CPF reference

The same comparison has been performed with the SP and TLE orbits. Figure 3-6 show that for both SP and TLE references the errors have a significant trend. SP errors are much larger than those resulting from calibration with CPF reference, while TLE error is one order of magnitude larger than the SP one. It is also evident that the along track mean deviation is far from zero.

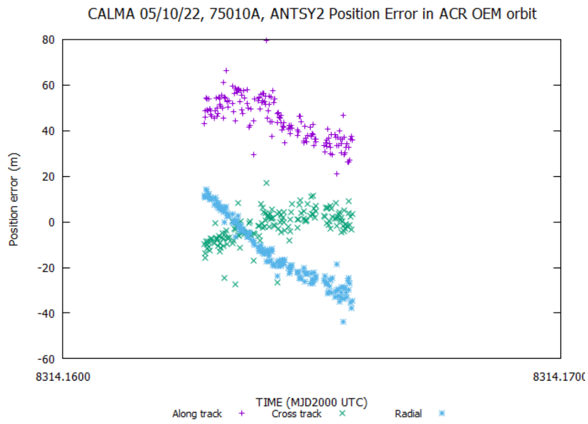

Figure 3. SP orbit deviations from Antsy 2 observations for Starlette satellite in ACR frame

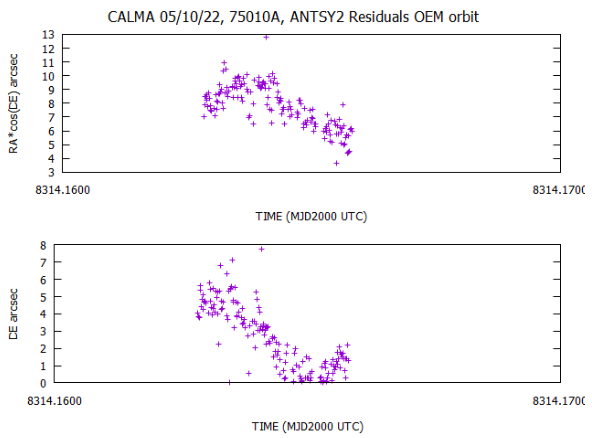

Figure 4. SP orbit deviations from Antsy 2 observations for Starlette satellite in Right Ascension and Declination

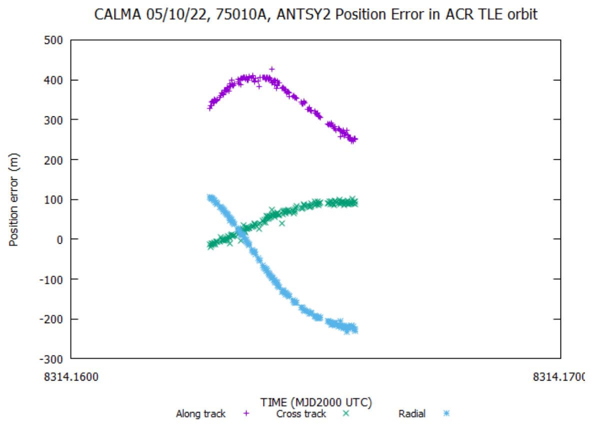

Figure 5. TLE orbit deviations from Antsy 2 observations for Starlette satellite in ACR frame

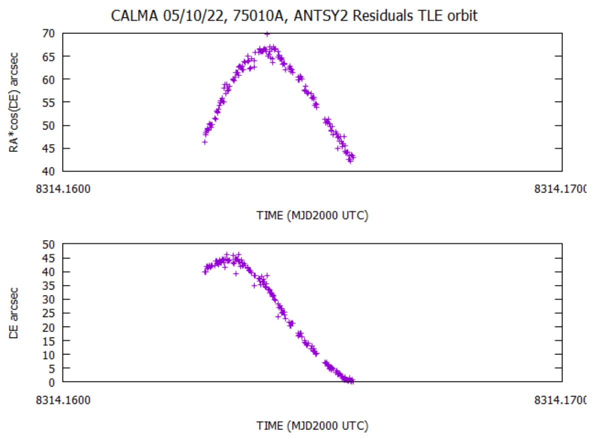

Figure 6. TLE orbit deviations from Antsy 2 observations for Starlette satellite in Right Ascension and Declination

4.2 Stella

In a way analogous to the case of Starlette, a calibration has been performed using Stella satellite CPF reference.

Figure 7-8 show results consistent with the previously analysed case. For Stella satellite, the along-track component is similar to the cross-track, and all components have mean close to zero with no apparent trend.

Right Ascension and Declination deviations in Figure 8 present most values below 3 arcsec.

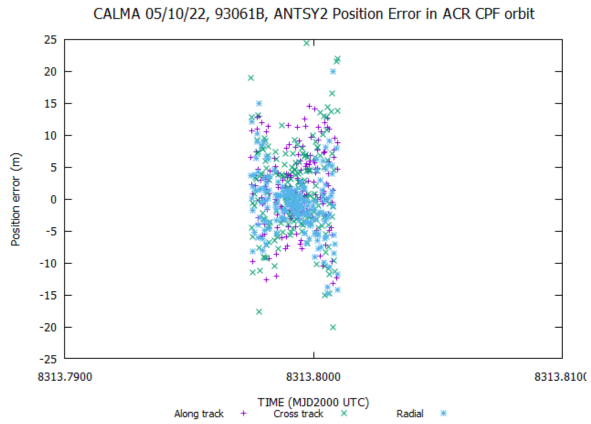

Figure 7. Calibration results in ACR frame for Stella satellite against CPF reference

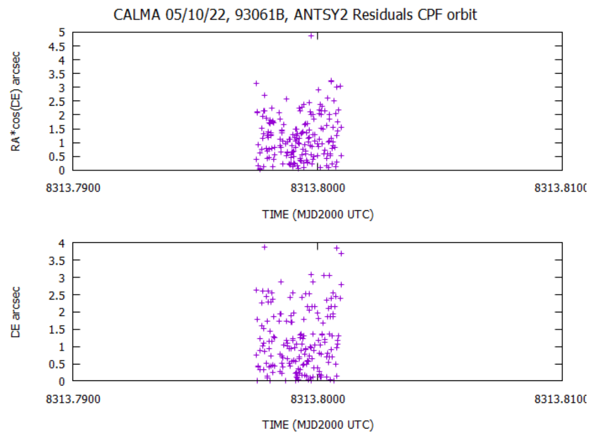

Figure 8. Calibration results in right ascension and declination for Stella satellite against CPF reference

The results obtained with SP and TLE orbits (Figure 9-12) are consistent with the previously analysed case of Starlette. The SP orbit is much more precise than TLE, however it still presents evident trends.

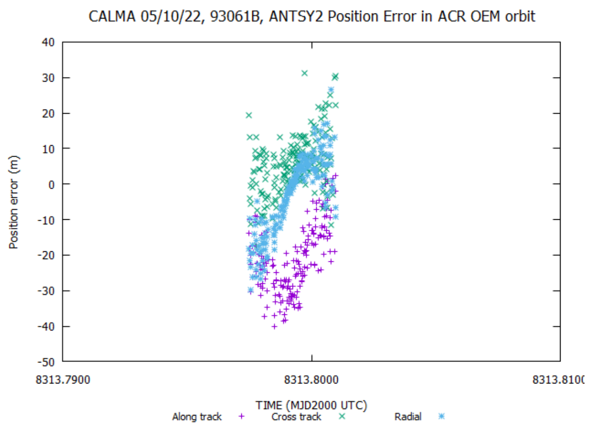

Figure 9. SP orbit deviations from Antsy 2 observations for Stella satellite in ACR frame

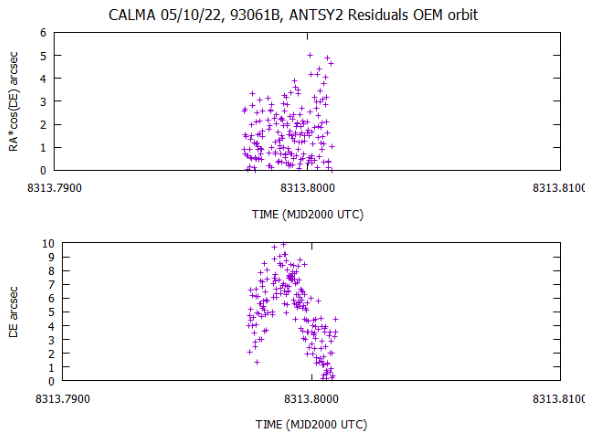

Figure 10. SP orbit deviations from Antsy 2 observations for Stella satellite in Right Ascension and Declination

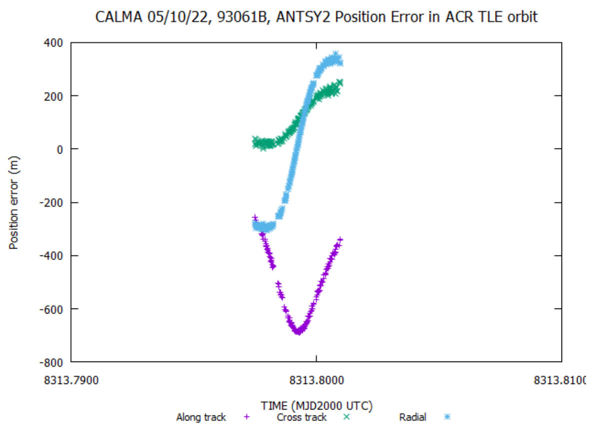

Figure 11. TLE orbit deviations from Antsy 2 observations for Stella satellite in ACR frame

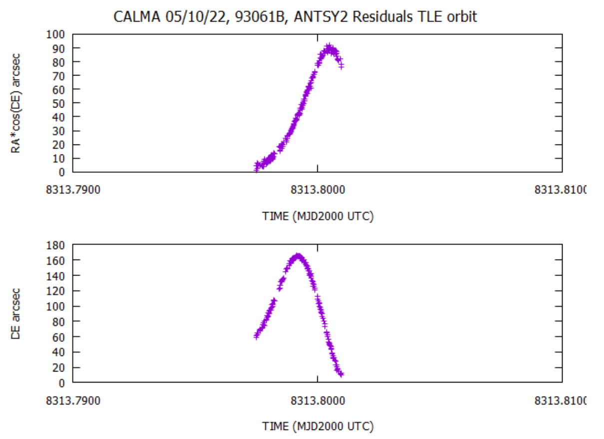

Figure 12. TLE orbit deviations from Antsy 2 observations for Stella satellite in Right Ascension and Declination

5 LEO OBSERVATION CAMPAIGN RESULTS

The observation campaign, to acquire an aleatory sampling of objects in LEO region, has involved 3 nights. In total 402 different objects have been observed. Table 1 shows the number of observed objects per night. Some objects were observed in more than one night.

Date	22-09-30	22-10-01	22-10-04
N. of Obs.	137	182	173

Table 1. Number of observed objects per night

Observed objects have been analyzed in further detail, resulting in 277 with apogee below 2000 km of altitude.

Figure 13 and Figure 14 show the objects apogees and perigees distribution with size. Raw size has been obtained from Satcat [2] splitting small objects if RCS < 0.1 m^2, medium if 0.1 m^2 < RCS < 1 m^2, large if RCS > 1 m^2.

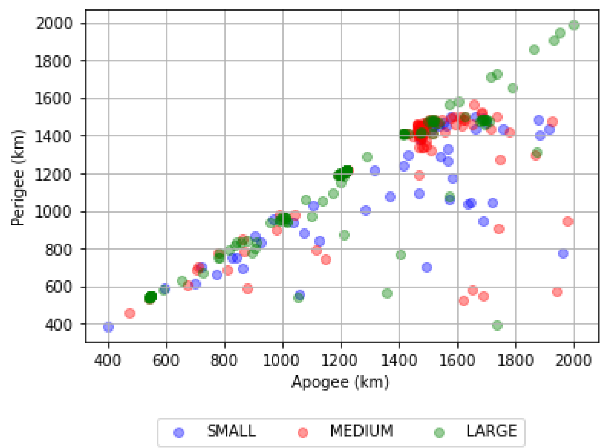

Figure 13. Observed LEO objects apogees and perigees

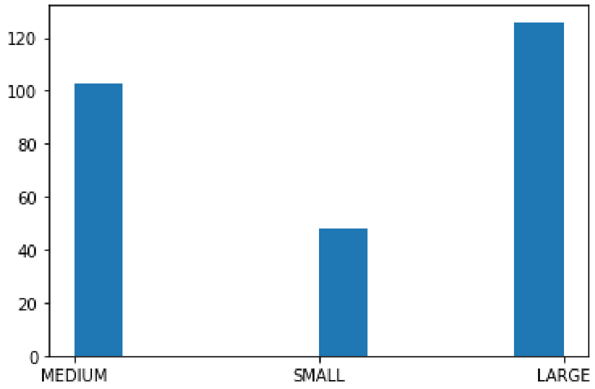

Figure 14. Number of observed LEO objects per size

6 RESULTS

The Right Ascension and Declination deviations of the latest updated SP and TLE orbits against the available observations have been computed for the three nights (Figure 15-16)

TLE deviations are on average larger than those of the SP catalogue. However, in some cases the SP orbits have shown larger discrepancies in comparison to the TLE.

For all nights, some objects present much larger deviations than average, both for SP and TLE catalogues.

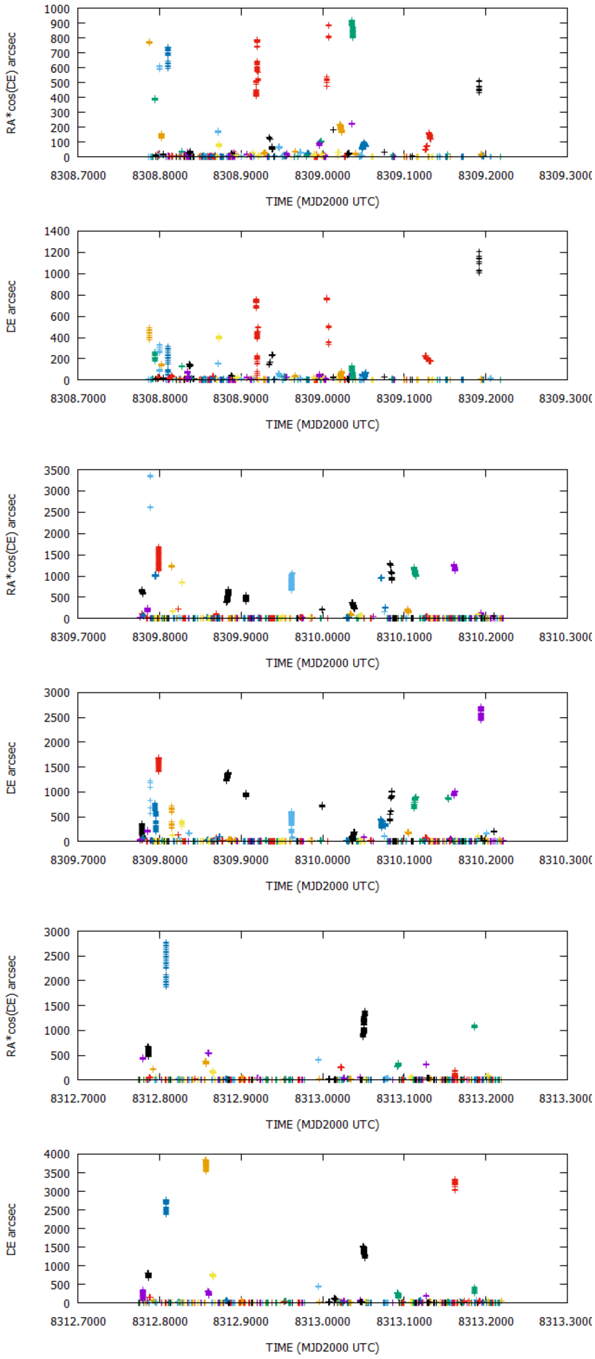

Figure 15. SP catalogue Right Ascension and Declination deviations against observations on 2022-09-30, 2022-10-01, 2022-10-04

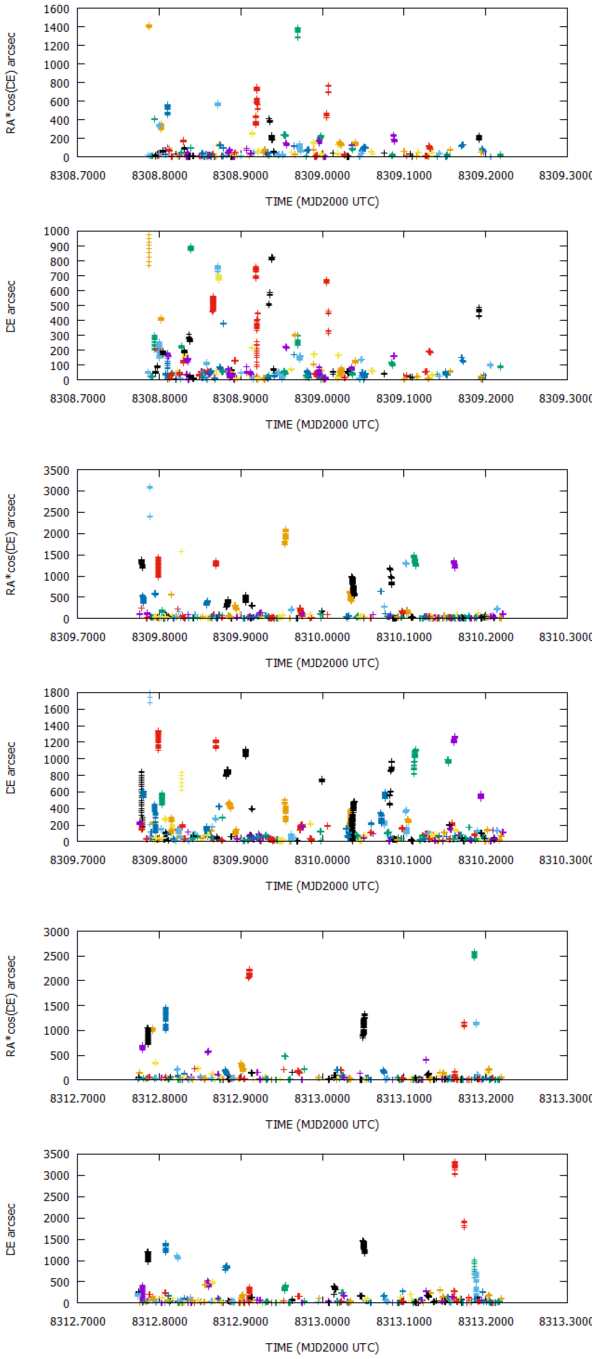

Figure 16. TLE catalogue Right Ascension and Declination deviations against observations on 2022-09-30, 2022-10-01, 2022-10-04

A more detailed analysis has been conducted on the objects with apogee < 2000 km. For these objects, Figure 18-19 show the deviations of reference SP and TLE orbits from Antsy 2 measurements, according to the objects eccentricities, in the along-track and cross-track components. Each point represents the mean value computed by considering all the observations acquired in a pass for the given object.

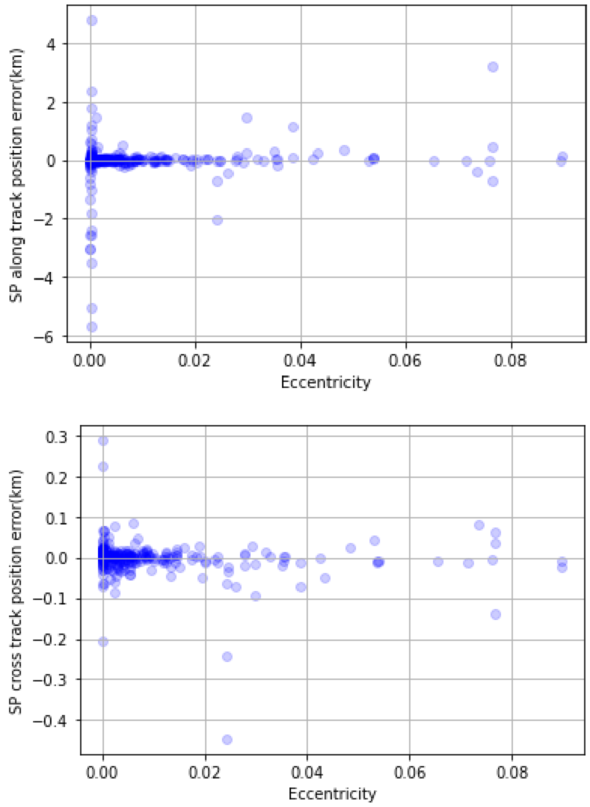

Figure 17. SP orbits along and cross track-errors vs ecc.

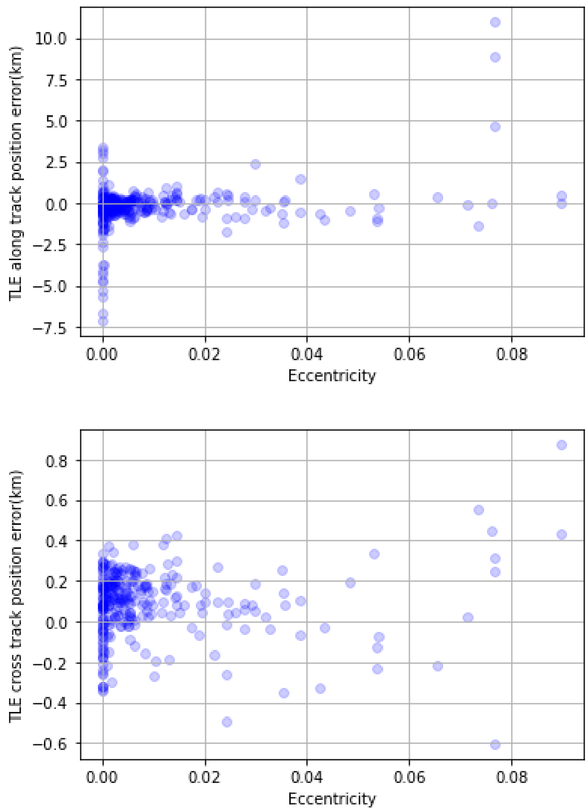

Figure 18. TLE orbits along and cross-track errors vs ecc

Figure 19 represents the along and cross-track deviations of SP vs TLE orbits. As in the previous case, each point represents the mean value computed along the observed pass. As expected, TLE catalogue clearly show larger errors than the SP one.

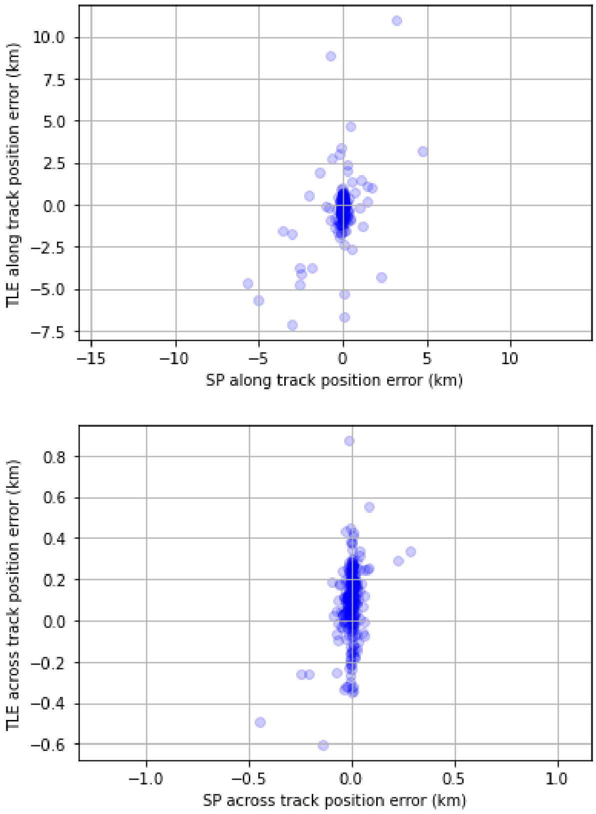

Figure 19. SP vs TLE along and cross-track errors

Figure 20 show the mean deviations for each observed object in terms of Right Ascension and Declination.

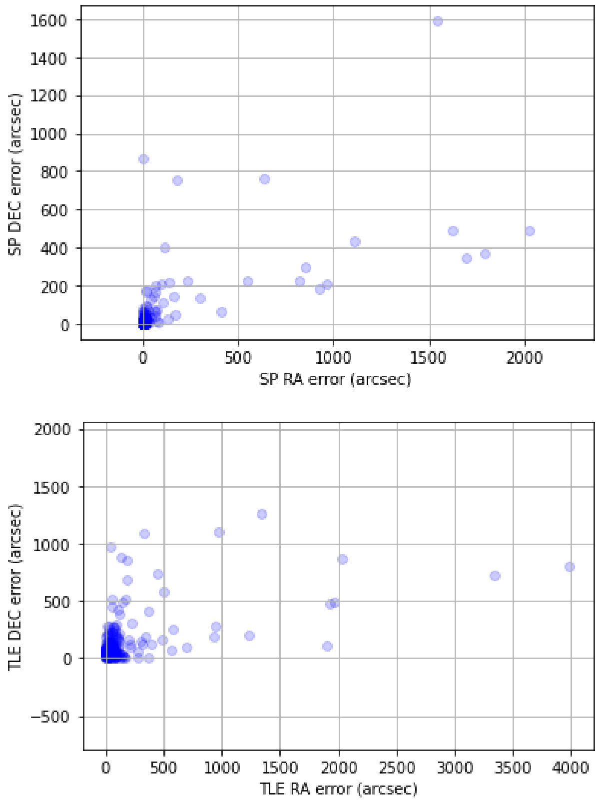

Figure 20. RA and Dec errors for SP and TLE orbits

7 CONCLUSIONS

In the along-track direction, SP catalogue have mean deviations of -0.047 km, +/-0.765 km std, while deviations of TLEs are -0.222 km, +/-1.458 km std. In cross track, SP catalogue have mean deviations of -0.002 km, +/-0.046 km std, and TLEs 0.090 km, +/-0.168 km std.

Previous values correspond very roughly to a +/- 131 arcsec pointing errors for SP, and a +/- 250 arcsec for TLE.

According to the results, there are no evident trends when comparing the deviations of the different catalogues correlations for the observed population.

8 REFERENCES

1. Raul Domínguez-González, Noelia Sánchez-Ortiz, Holger Krag, Johannes Gelhaus *Analysis of uncertainties of catalogued orbital data for the update of the ESA DRAMA ARES tool*, International Astronautical Congress, 2012

2. https://space-track.org

3. https://ilrs.gsfc.nasa.gov/ International Laser Ranging Service

4. Noelia Sánchez-Ortiz, Jaime Nomen Torres, Raúl Domínguez-González, Nuria Guijarro, Daniel Lubián Arenillas *Operational observations of LEO objects with optical sensors: Extended observational campaigns* International Astronautical Congress, 2019