COORDINATED OPTICAL GEO SURVEY FOR EUROPEAN SSA PRECURSOR SERVICES

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ABSTRACT

An important objective in the framework of the European Space Agency (ESA) Space Situational Awareness (SSA) Programme is the acquisition of observations by federating existing sensors in Europe. Such observations will be required as input to currently developed SSA precursor services. Observations from a series of European optical sensors were acquired during a coordinated campaign and were used to emulate the build-up and maintenance of a temporally and spatially limited object catalogue. The catalogue was designed to concentrate on objects in the geo-stationary orbit region (GEO). Given the very different nature of the participating sensors both, in terms of their performance characteristics and operational use, a major challenge consisted in coordinating the operation of these sensors and fusing the heterogeneous data that was generated.

The paper will present the procedures used to initiate and maintain a limited GEO catalogue without the use of external information. The discussion will include the scheduling of the heterogeneous sensor network, the processing of the observations from the observing sites and their integration into a successive catalogue. Results from the actual observation campaign will illustrate the performance of the very limited sensor network and the used cataloguing procedures, as well as the temporal and spatial limitations of such a catalogue.

1. INTRODUCTION

An important objective in the framework of the ESA's Space Situational Awareness (SSA) Programme is the acquisition of observations by federating existing sensors pertaining to organisations within ESA's member states. Such observations will be required as input to currently developed SSA precursor services. Observations performed in the context of this work shall be used to emulate the build-up and maintenance of a temporal and spatially limited object catalogue. Within the scope of this study the catalogue focusses on objects in the geostationary orbit region (GEO).

Several European sensors were made available to provide observations. Given the very different nature of these sensors – both, in terms of their performance characteristics and operational use – a major challenge consisted in coordinating the operation of these sensors and fusing the heterogeneous data.

The main tasks within this study consisted in the following:

1. The identification of the temporal and spatial boundaries of this catalogue, taking into account the target size of the objects to be detected and the longitudinal extent of the coverage provided by the available European sensors.
2. To plan and execute the observation nights required for each of the sites chosen, in order to be able to maintain the catalogue to a sufficient level. An important aspect consisted in the cold-start nature of the catalogue.
3. To process the observations from the observing sites and integrate them into successive catalogue iterations over the duration of the activities. These catalogue iterations were delivered to ESA in regular intervals.
4. To communicate with the observation sensors the planned opportunities for observing, collect the observation results and integrate them into the process.
5. To provide the observation measurements and determined orbit data to ESA.

2. CAMPAIGN PREPARATION & EXECUTION

A series of 4 small aperture (20-45cm) survey sensors and two 1m-class sensors for follow-up operations were available in this observation campaign. The survey sensors had varying capabilities. In particular their fields of view ranged between 1.7 to 4.5 degrees. 6 to 18 nights per sensor were available within the 3.5 month observation campaign. Figure 1 shows the visibility zones at GEO altitude for the 6 sensors taking part in the observation campaign.

The baseline observation schedule consisted in distributing the available survey sensors nights over the entire observation period taking into account sensor availability. There were intentionally no parallel observations foreseen in order to best cover the entire period by at least one sensor at a time. The baseline plan was then adapted each day to take into account sensor outages due to weather conditions.

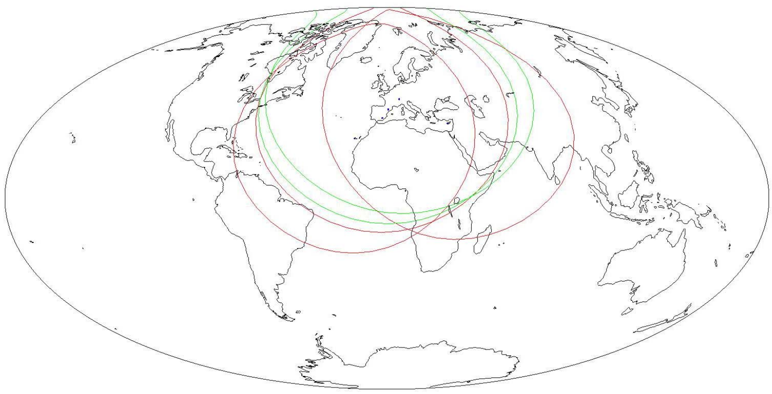

Figure 1: Visibility zones of the 6 sensors taking part in the observation campaign (zone at 42164km altitude; >30° minimum elevation).

It was decided not to impose a common survey strategy but rather to let each sensor use their established strategies in order to best exploit the specific capabilities.

Given the geographically limited extent of the sensor network, as well as the very limited number of sensors, it was obvious that the catalogue build-up and maintenance would be extremely challenging. In particular a high risk existed to lose drifting objects and to miss-tag co-located and manoeuvring satellites, due to significant observation gaps.

A major effort during the preparation phase was devoted to the definition of the communication procedures between the coordination, data collection and processing entity at the Astronomical Institute of the University of Bern (AIUB) and the individual sensors. This included the definition of formats for the sensor input parameters like the ephemerides for the calibration objects and the log files to be delivered after each observation night. The sensors each delivered the observation data (epoch and astrometric positions of detected objects) in their own format. Procedures to convert these data into the AIUB-internal formats and finally in to the standard CCSDS TDM format had thus to be developed and tested. The detailed planning was then iterated with the sensors and dry runs executed to validate the communication procedures and the correct decoding and conversion of data. The daily standard communication procedure between the coordinating entity AIUB and the sensors is shown in Figure 2.

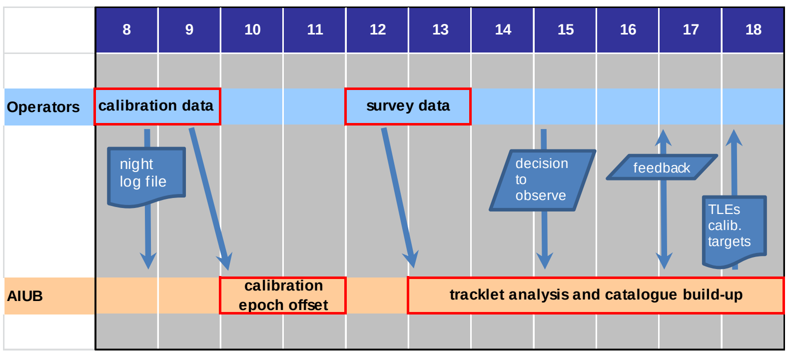

Figure 2: Daily standard communication procedure between the coordinating entity AIUB and the sensors.

Figure 3 shows the actual observations performed by the individual sensors over the 3.5 month observation campaign.

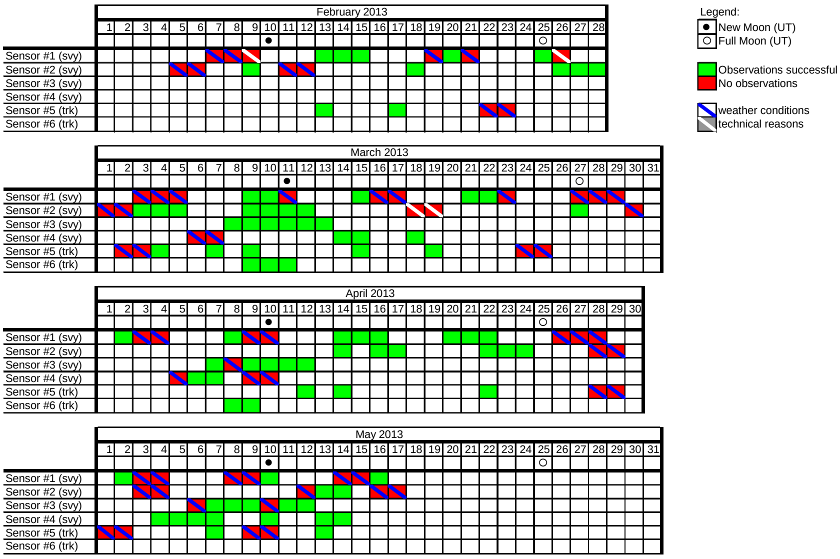

Figure 3: Actual observations performed by the individual sensors over the 3.5 month observation campaign.

The build-up and maintenance of the orbit catalogue was performed each time new observations were available. The catalogue was updated by correlating new observations with catalogue. Each time a new series of consecutive observations, a so-called tracklet, was identified to belong to an object already contained in the catalogue, a new orbit for this object was determined by combining the new and the existing tracklets. Tracklets which could not be associated to existing objects were mutually correlated to identify potential new objects. An overview of the catalogue build-up and maintenance procedure is given in Figure 4. It is important to note that no external information was used to build-up and maintain the catalogue throughout the entire observation campaign.

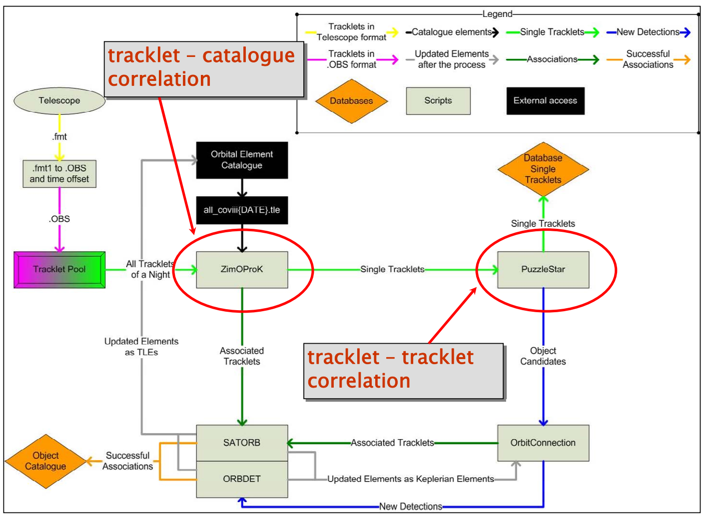

Figure 4: Catalogue build-up and maintenance procedure.

3. DATA VALIDATION & CALIBRATION

Data validation and calibration turned out to be a critical and mandatory task. In order to assess the data quality (astrometric error) and to calibrate potential epoch registration biases, the sensors were tasked for each night to acquire observations of GNSS satellites (GPS and GLONASS) which served as “calibration objects”. These observations were then compared with precise reference orbits provided by the Center of Orbit Determination in Europe (CODE) located at the AIUB. An example of the epoch bias calibration is shown in Figure 5.

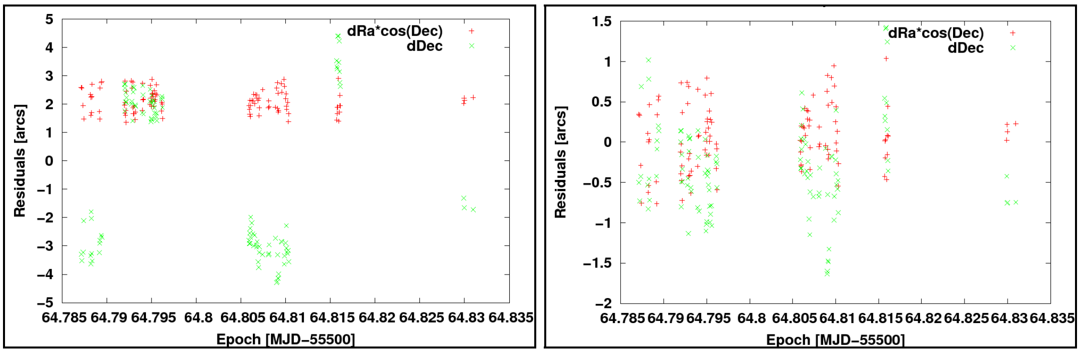

Figure 5: Example of epoch bias calibration. Residuals of observations of calibration objects before (top) and after epoch bias calibration (epoch bias of ~100ms).

4. SUMMARY OF OBSERVATION CAMPAIGN

A total of 63038 tracklets were acquired during the 3.5 months of the observation campaign. Out of these, 21620 were associated with 2136 so-called analyst objects. The total observation arc lengths range from a few hours up to 100 days. 382 analyst objects had arcs exceeding 3 days. An a posteriori correlation of the catalogue with the publicly available TLE catalogue provided by USSTRATCOM revealed that a total of 760 TLE-objects were observed and catalogued during this campaign.

It is important to notice that “analyst objects” are not necessarily identical with real objects. Several different analyst objects may in fact turn out to be the same real object, and vice versa the observations associated with one analyst object could stem from more than one real object. Such miss-tagging may occur in cases where the observations arcs were very short (< 1day), where the object was executing manoeuvres, or where drifting objects were not within the visibility sector for longer time intervals. Also prone to miss-tagging are satellites co-located in the same longitude slot (also called “clusters”).

The cumulative number of analyst objects in the catalogue throughout the observation campaign is given in Figure 6. Figure 7 shows a histogram of the observation arc lengths (left) and the distribution of analyst objects as a function of orbit type and observation arc length (right).

The distribution of the eccentricity as a function of mean motion (Figure 8) shows the well-known classes of GEO, GTO and MEO objects, but also two additional “classes” not related to real orbits (see labels in the figure). The structure on the left hand side with objects showing mean motions <1rev/day and eccentricities between 0.05 and 0.9 can be attributed to objects with two tracklets only and arc lengths of 1-2 hours. In these cases the eccentricities are highly correlated with the mean motion and almost degenerate. The second structure outlined in Figure 8 is also associated with objects with two tracklets only. In these cases the eccentricity was forced to 0 during the orbit determination (circular orbit determination).

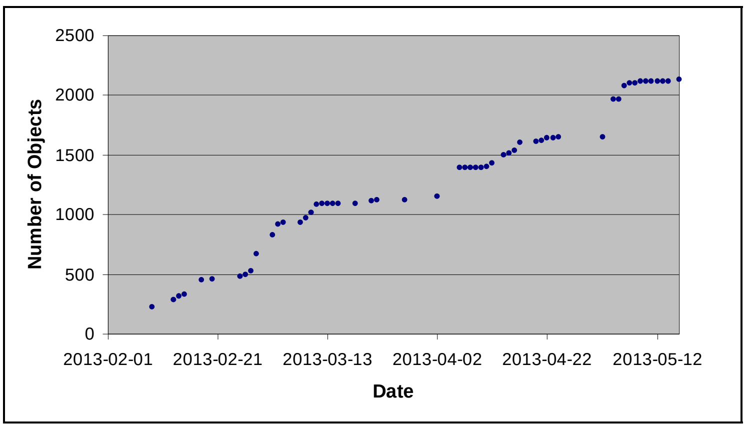

Figure 6: Cumulative number of analyst objects in the catalogue throughout the observation campaign.

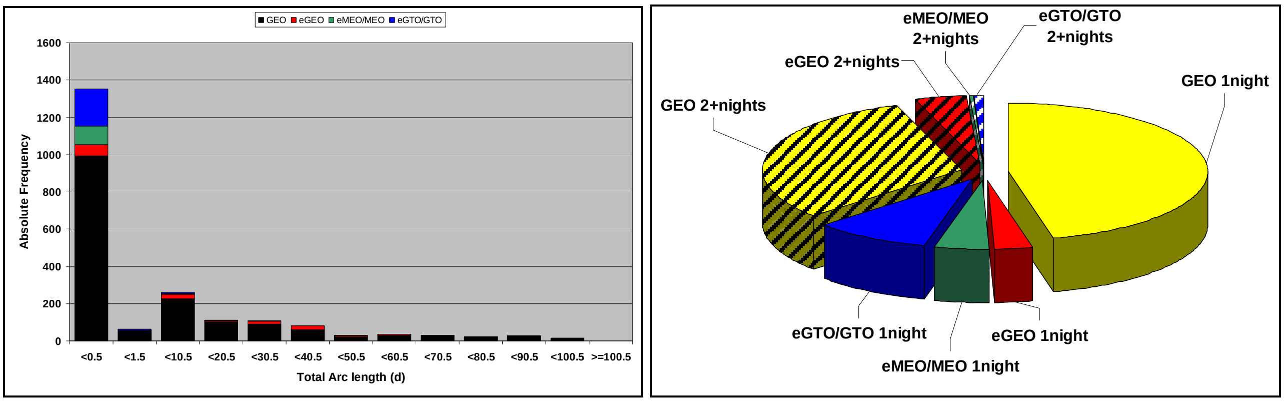

Figure 7: Left: Observation arc lengths of the analyst objects in the catalogue. Right: Analyst objects as a function of orbit type and observation arc length.

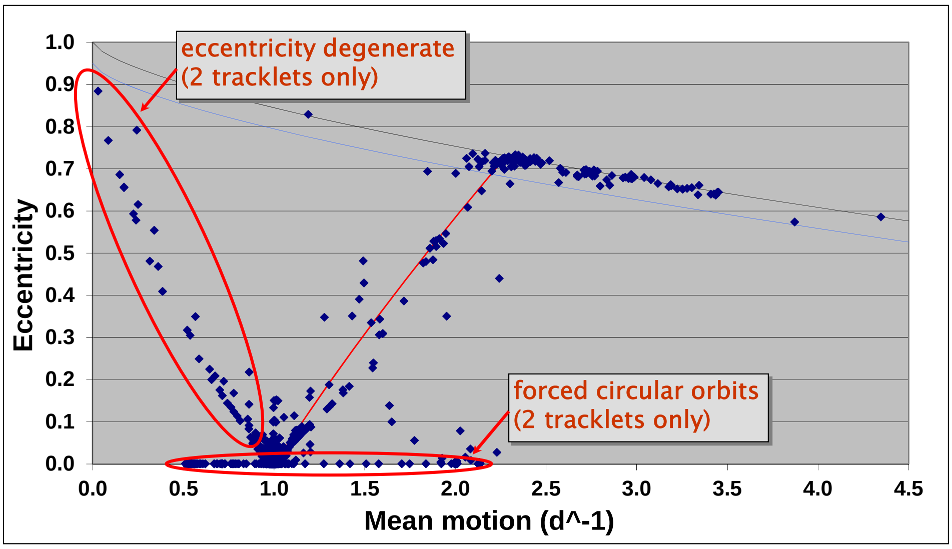

Figure 8: Eccentricity as a function of mean motion for the analyst objects.

5. CONCLUSIONS

Successful autonomous initiation and maintenance of a catalogue of GEO objects has been demonstrated. The data collected in the 3.5 month observation campaign resulted in a catalogue of 2136 analyst objects in GEO, GTO and MEO orbits. An a posteriori correlation with the public version of the USSTRATCOM TLE catalog showed that 760 TLE objects were observed and catalogued.

The experimental campaign also demonstrated the successful coordination of a loose network of sensors with mostly small apertures and of significantly different nature and operation concepts. Data validation and calibration was identified as a mandatory task to assure the data quality and to monitor the performance of the sensors.

The cataloguing experience gained, together with the acquired data will significantly contribute to the development and testing of the novel European SSA services.