Optical Tracking Extended Network in Support to Operational Flight Dynamics and Conjunction Analysis for Meteosat

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Within the Meteosat Second Generation (MSG) programme, the Flight Dynamics team at EUMETSAT operationally performs routine orbit determination runs, using S-band range measurements, received from proprietary ground stations for the 4 geostationary satellites in this fleet. This is done also for the last satellite of the first generation, Meteosat-7. Occasionally, directional measurements are also received from a number of optical tracking sensors on ground; they can be processed by the FDS in parallel, together with the available ranging data, within the same least-squares batch estimation process. This allows obtaining particularly robust solutions, where the system becomes also sufficiently overestimated to solve additional relevant auxiliary parameters and perform an accurate fine tuning of the different measurement biases. In the past years EUMETSAT performed different trials with different service providers, operating 1 or 2 telescopes only. During the last two years, the focus was on testing solutions, making use of multiple telescopes, to better cope with weather diversity and very short term tracking requests. This paper provides some recent examples of the use of accurate angular measurements for the EUMETSAT operational geostationary satellites. The specific case of the support provided for the re-orbiting operations of Meteosat-7 is also illustrated.

Key Words: optical tracking, directional observations, orbit determination, geostationary

1. Introduction

A series of optical tracking campaigns of Meteosat satellites was previously carried out in 2014. [1)]

Since 2015, optical directional observations of particularly high-quality for the EUMETSAT operational geostationary satellites have been repeatedly received from two independent networks (see Fig. 1). The collected data were used intensively in orbit determination performance assessments. An analysis of the data sets, involving multiple optical measurement sources providing data in parallel, was performed to assess possible advantages over single optical measurement source scenarios.

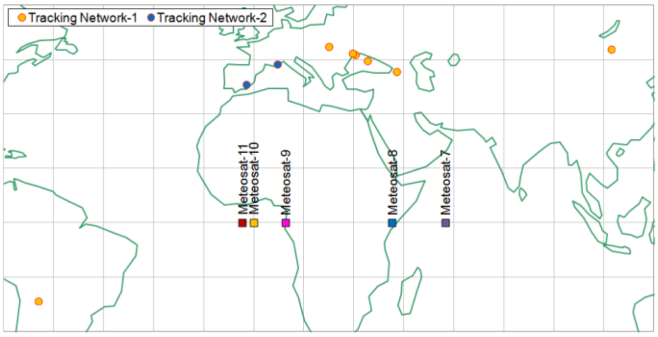

Fig. 1. Optical tracking networks used in support of Meteosat operations during the period 2015-2017.

2. Results from Tracking Network-1

An exhaustive analysis of two tracking campaigns, carried out in the periods between 06 May and 17 May 2016 and between 26 June and 08 July 2016 was provided to EUMETSAT by GMV/ISON.[2)] The processing has been carried out with Space Surveillance and Tracking Orbit Determination Software (*sstod*).[3)]

Figure 2 shows an example of measurement residuals obtained in an orbit determination run, using range measurements from two EUMETSAT ground stations and angular data from 7 different optical sensors.

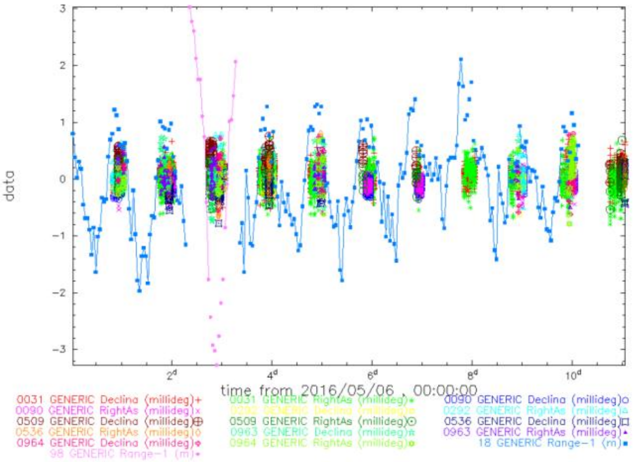

Fig. 2. An example of final residuals obtained for a Meteosat-10 orbit determination run, using data fusion of range measurements from 2 ground stations and angular data from 7 optical sensors.

Figure 3a shows the results obtained from a first set of independent orbit determination assessments. The orbit comparisons show the differences between orbits, determined with range and tracking data fusion, and the operational orbits, determined on the basis of ranging data only.

A second set of orbit determination comparison results is also provided, with the aim of showing the possible margins of improvement of the operational range-only solutions, when using fine tuned range biases. With the data fusion of range and tracking measurements, a re-estimation of the range biases was performed. Significant improvements were then achieved for orbit determination runs repeated using only range measurements. Figure 3b shows the differences between orbits, determined with range and tracking data fusion, and the orbits, determined with only ranging data and using updated bias estimates.

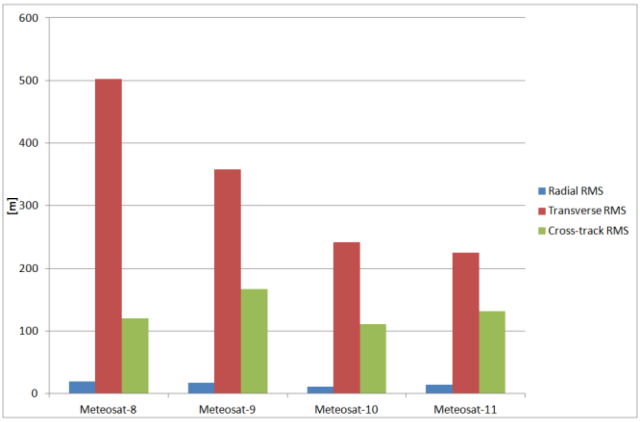

Fig. 3a. Orbital differences between data fusion orbits and operational orbits, based on ranging data only.

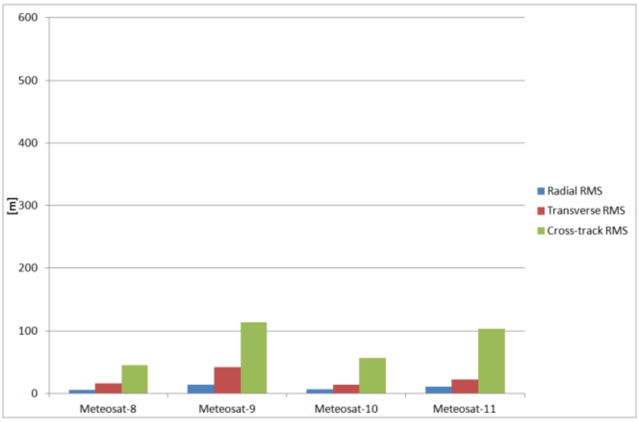

Fig. 3b. Orbital differences between orbit determination runs, using range and tracking data fusion, and the determined orbits, based only on ranging data with updated bias estimates.

The comparison between Figure 3a and Figure 3b exemplifies very well how the fine tuning of the range biases can improve the operational orbit determination performance.

3. Results from Tracking Network-2

A second network, $^{4)}$ consisting of two sensors operated by Airbus Safran Launchers, was employed for a longer period, and provided tracking data for all operational Meteosat satellites between 14 November 2016 and 27 January 2017.

During this period, the collected measurements were routinely used in EUMETSAT in orbit determination runs, using the operational FDS software, merging the ranging data of the ground stations and the angular data from the optical sensors.

Figures 4a and 4b show the resulting standard deviations of the angular data final residuals for three reference runs, performed for the different satellites, at the beginning, in the middle and towards the end of the covered period.

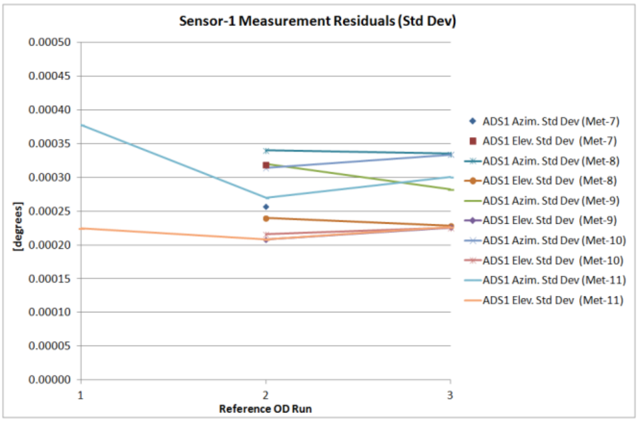

Fig. 4a. Standard deviations of the angular data residuals for Sensor 1 in three reference runs, at the beginning, in the middle and towards the end of the covered period.

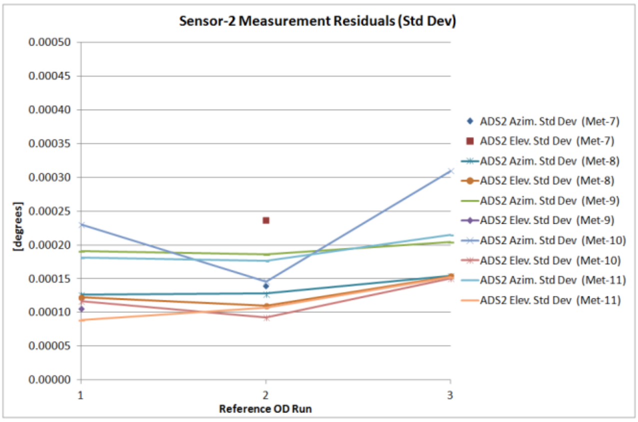

Fig. 4b. Standard deviations of the angular data residuals for Sensor 2 in three reference runs, at the beginning, in the middle and towards the end of the covered period.

Figure 5 shows an example of orbit comparisons made when determining the orbit for Meteosat-10 using different sets of measurement data: only range measurements from a single ground station, only angular data from one or two optical sensors, and fused measurement data sets. Each determined orbit was then compared to the operational orbit, determined from ranging data provided by two ground stations, and the position deltas were computed over a common 24-hour reference arc.

The results obtained during the tracking campaign with Network-2 showed that the quality of the received measurements was fully comparable to the data received during the campaigns with Network-1. The testing allowed then also demonstrating the capability of the operational FDS software in EUMETSAT to obtain accurate orbit determination solutions, also when using only angular observations from a single tracking sensor, without any range measurement from the ground stations. In particular, such solutions proved significantly superior to solutions obtained using a single ranging station, which were already known to be affected by reduced orbit observability. Periodic ground station maintenance work or occasional malfunctions of the equipment on ground can cause sometimes longer outages of range measurement data from one of the two used stations. The availability of high accuracy optical tracking data provides therefore a significantly improved robustness and ensures that the operational orbit determination function remains substantially unaffected, also in the case of a complete outage of range measurements.

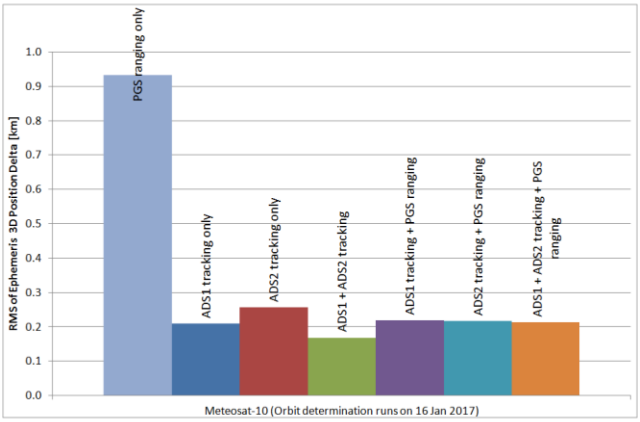

Fig. 5. Orbital differences between the operational orbit and orbits determined using different sets of available measurement data.

Compared to the tracking campaigns carried out with Network-1, which included 7 available sensors, Network-2 consisted of only 2 sensors. Occasionally, both sensors became unavailable during the same night, due to poor weather conditions, causing longer outages of tracking data. This was identified as a potential disadvantage, in particular for the cases in which the need of tracking data is focused on very specific time periods, like prior to high-risk conjunctions or around manoeuvres. Airbus Safran Launchers (ASL) have meanwhile increased their network to 4 sensors and are currently planning for additional ones.

During the agreed period of provision of regular tracking data for the operational Meteosat satellites, an on-demand tracking service for other objects of interest was also arranged with the operator of Network-2. This was specifically intended to provide support for critical proximity assessments around predicted close encounters. An independently maintained database of space objects allowed the operator to meet the agreed 2-hour response time requirement for such requests (except the known limitation that the maintained database did not include controlled objects and objects in GTO).

4. Support for Conjunction Analysis

The following example illustrates the potential usefulness of the availability of independent observations, to support assessments of close encounters.

Provided on a regular bases with updated ephemeris data for the operational Meteosat satellites, CNES is routinely screening and identifying potentially hazardous conjunctions for EUMETSAT and occasionally autonomously schedules also dedicated optical tracking campaigns, aimed to provide an improved knowledge of the orbit of the secondary object.

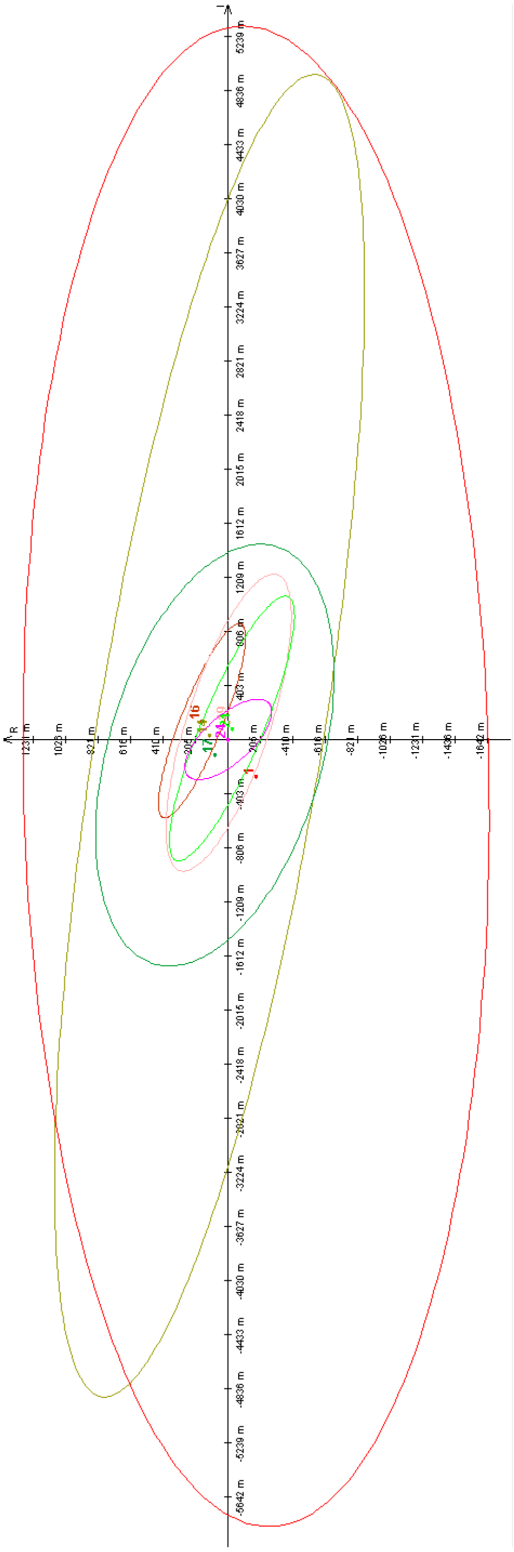

Fig. 6. Uncertainty of the INTELSAT 3-F7 position in the along-track and radial directions, for estimates provided within the last 10 days before the predicted time of the closest approach with Meteosat-11 on 1st November 2016 (plot provided by CNES, JAC).

INTELSAT 3-F7 (1970-032A) is an abandoned geosynchronous object, librating around the Eastern stable longitude point (75°E), between 4°W and 142°E, with a period of about 4 years.

At its turning point of the longitude drift during November 2016, INTELSAT 3-F7 was exactly inside the longitude slot used by Meteosat-11. The two satellites remained then in relatively close vicinity for a prolonged period of time, within which two close encounters were predicted, respectively on 1st November 2016 and 4th December 2016. The main difficulty in assessing the risk of the two conjunctions was the relatively large uncertainty on the INTELSAT 3-F7 orbit, as provided by JSpOC in the first alert messages, generated several days before the encounters.

For the close encounter on 1st November 2016, with the smallest predicted minimum range of less than 1500 m, a dedicated optical tracking campaign was therefore requested to a number of tracking sensor operators, with the aim of obtaining better orbital data for INTELSAT-3-F7. Improved orbit determination results, attained in the last few days before the encounter, allowed then deciding not to perform an avoidance manoeuvre, which would have otherwise disrupted normal routine operations. The decision was taken based on cross-comparison of the available JSpOC CDMs with two different conjunction analyses, based on data coming from independent optical sensor networks.

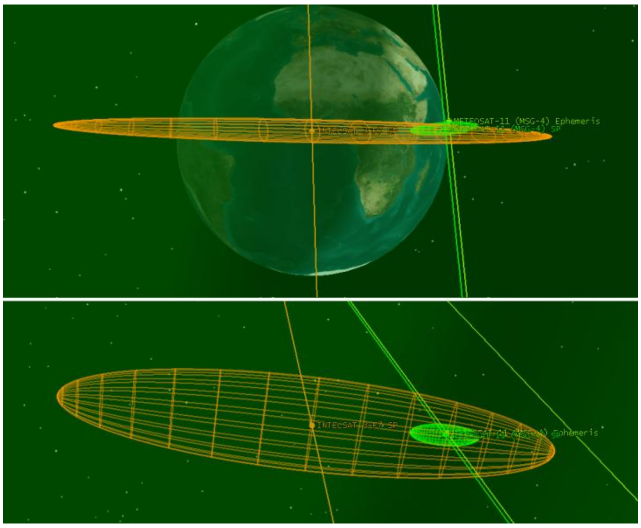

Fig. 7. Graphical representation of the JSpOC CDM data for the conjunction on 4th December 2016, between INTELSAT 3-F7 and Meteosat-11, as available four days before the close approach (plot provided by the Space Data Center, STK viewer).

Figure 6 shows the progressive reduction of the uncertainty of the INTELSAT 3-F7 position, for estimates provided within the last 10 days before the predicted time of the closest approach on 1st November 2016. All plotted data are based on CDMs provided by JSpOC, except of the contours labelled with numbers 16 and 24, which were independently estimated by CNES, respectively at 4 days and at 1 hour before the conjunction event (the centre point of the latest estimate is also used as origin of the plot).

Figure 7 shows the geometry of the similar approach between the two satellites, occurred on 4th December 2016. Also in this case, a reduction of the initially large position uncertainty in the along-track direction for INTELSAT 3-F7 could be observed within the last 3 days, so that the close encounter could be finally declared safe and not needing an avoidance manoeuvre.

5. Support for Meteosat-7 Re-orbiting

After providing almost 20 years of service, Meteosat-7, the last satellite of the first generation series, reached its end of life and started a sequence of re-orbiting manoeuvres on 3rd April 2017. Figure 8 is a schematic representation of the sequence of orbit raising manoeuvres, planned in order to move the satellite away from the GEO protected region, in compliance with the International Space Debris Mitigation Standard (ISO 24113). Part of the orbital thrusts is executed using a single thruster configuration, to as well reduce the satellite spin rate to dissipate kinetic energy, without having any additional cost of fuel.

Due to malfunctions onboard the ageing satellite and limitations in the supporting ground segment, the availability of ranging data was restricted to measurements collected by a single available antenna on-ground. In order to provide sufficient redundancy for orbit determination, a dedicated optical tracking campaign was therefore planned, to be carried out throughout the period of the re-orbiting manoeuvre sequence execution. Up to 7 sensors of Network-1, already described in the beginning of this paper2), ensured a very good coverage during the performed campaign (Figs. 9 and 10).5) The combined processing of range and optical tracking data was mainly aimed to improve the determination of the performance deviations for the executed manoeuvres.

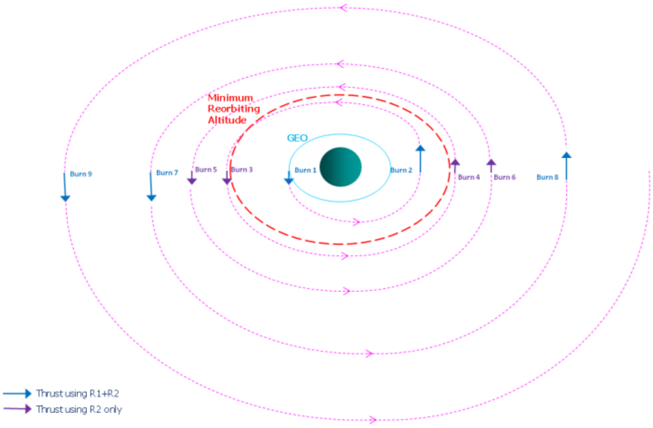

Fig. 8. Schematic representation (drawing is not to scale) of the planned sequence of up to 9 manoeuvres for the End-Of-Life re-orbiting of Meteosat-7.

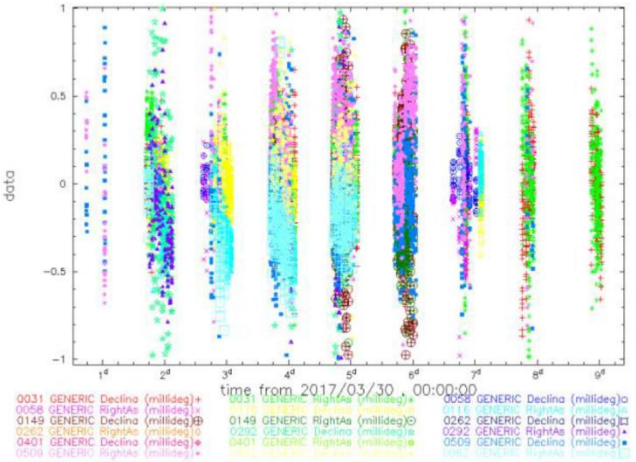

Fig. 9. Angular data residuals obtained for a Meteosat-7 orbit determination run, during the satellite re-orbiting operations, using data fusion of range measurements from one ground station and angular data from 7 optical sensors.

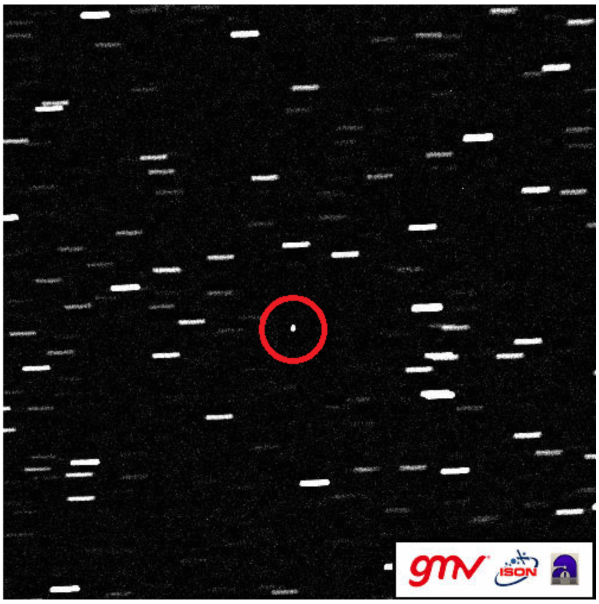

Fig. 10. Meteosat-7, as captured by one of the optical sensors used in the tracking campaign in support of the satellite re-orbiting operations between 3rd and 6th April 2017.

The most critical of the manoeuvre performance assessments was the one after the first of the re-orbiting burns. Due to the unprecedented large size of the burn, the uncertainty on the actual manoeuvre performance was relatively high. Optical observations collected immediately after that manoeuvre allowed confirming that the orbit raising objectives would be then fully met with the subsequent manoeuvres, as planned.

Meteosat-7 terminated its sequence of orbit raising manoeuvres on 6th April 2017, reaching an orbit with perigee and apogee respectively 515 km and 607 km above GEO.

6. Conclusion

Separate optical tracking campaigns, involving two independent sensor networks, provided the opportunity of acquiring an extensive experience in the use of accurate directional observations in support of Meteosat operations.

The obtained results allowed successfully demonstrating the capability of the operational FDS software in EUMETSAT to obtain accurate orbit determination solutions, also when using only angular observations, without any range measurement from the ground stations. In particular, such solutions proved to be significantly superior to solutions obtained using ranging data from a single ground station.

The general benefits of the optical tracking measurements were found to be further enhanced, when using vast networks, having access to a large number of sensors. Such redundancy is essentially necessary to avoid potential impacts of adverse weather conditions on the availability of the data and becomes an important asset around time-critical operations, like manoeuvres, or specific cases of short notice close encounter alerts.

The support provided by one of such large tracking networks for the re-orbiting operations of Meteosat-7, during April 2017, proved to be another excellent example of the reliability and usefulness of optical directional observations for Meteosat operations.

Acknowledgments

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