ORBITS OF GEOSTATIONARY TV SATELLITES

ANDRZEJ DROŻYNER
Institute of Astronomy, Nicholas Copernicus University
Toruń, Poland

Abstract. In the frame of European cooperation among some stations (Brussels, Praha, Cagliari, Torino, Penc, Borowiec, Teddington, Metsahovi, Besançon and San Fernando) the method of time comparisons by a TV link has been used for orbit determination of the Eutelsat-F2 satellite. Observational stations are equipped with commercial TV receivers and high stability time services. The technique of observations is based on the registration of arrival times of synchronous pulses broadcast by the satellite. For this type of observations a special orbital software package (TOP-COGEOS) has been developed, which allows the determination of the dynamical state of the satellite and some additional parameters connected to applied observational technique.

1. Introduction

This paper deals with orbit determination for the geostationary satellite Eutelsat-F2. This satellite was used in the COGEOS Campaigns (International Campaign of Optical Observations of Geosynchronous Satellites). Since 1963 (first launch of the Syncom-1 satellite) the geostationary orbit was intensively used due to the (relatively) stationary position of satellites with respect to the Earth's surface.

Let us first of all explain the problem of orbit determination of a geosynchronous satellite using the COGEOS type of observations. In the frame of this project the method of time comparisons by TV link between European stations has been elaborated. The arrival times of synchronous pulses of the TV signal broadcast by the Eutelsat-F2 satellite are recorded at the European observatories (Brussels, Praha, Cagliari, Torino, Penc, Borowiec, Teddington, San Fernando and Metsahovi). These are equiped with commercial satellite TV receivers and high stability time services (GPS time system).

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2. Observation Technique

The observation technique is based on the interferometric principle. The COGEOS stations record synchronous signals transmitted by the Eutelsat-F2 satellite. Therefore, the range difference d_0 is the difference in the satellite range as measured from each of the ground stations on a given baseline (with respect to the reference station-Brussels):

$$d_O = c\,(T_B - T_S) \tag{1}$$

where c is the speed of the light, T_B the time at Brussels, when the ground station receives the signal, T_S the time at the COGEOS network station receiving the signal.

The measurement model for this type of observation is therefore:

$$d = \varrho_B - \varrho_S + B \tag{2}$$

where:

$$\varrho_B = c\,(T_B - t) = |\vec{r}(t) - \vec{R}(T_B)| \tag{3}$$

$$\varrho_S = c\,(T_S - t) = |\vec{r}(t) - \vec{R}(T_S)| \tag{4}$$

and ϱ_B is the topocentric range of the Eutelsat-F2 satellite from Brussels, ϱ_S the topocentric range from station S, t the satellite time (unknown: time when the satellite transmits the down-link signal), $\vec{r}$ the position of the satellite at time t, $\vec{R}$ the position of the ground station, B the constant bias on the measurement.

3. Light Time Modeling

For a geostationary satellite the topocentric distances give rise to signal travelling time (propagation time τ) of the order of 0.13 seconds. During this time the satellite moves about 400 meters in the inertial coordinate frame, and the Earth rotates about 50 meters. What is actually measured on ground stations are the times T_i, whereas the satellite time t is not known a priori. Therefore,:

$$t = T_i - \tau \tag{5}$$

where the propagation time τ is equal to:

$$\tau = \frac{\varrho}{c} = \frac{1}{c}\,|\vec{r}(T_i - \tau) - \vec{R}(T_i)| \tag{6}$$

Equation (6) is solved iteratively with respect to τ, starting from $\tau = 0$, until convergence is obtained.

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4. Partial Derivatives

Using relation (2) we have:

$$\frac{\partial d}{\partial p} = \frac{\partial \varrho_B}{\partial p} - \frac{\partial \varrho_S}{\partial p} \tag{7}$$

$$\frac{\partial d}{\partial B} = 1 \tag{8}$$

where p denotes an orbital (or force model) parameter, and

$$\varrho_i^2 = \left(\vec{r}(t) - \vec{R}(T_i)\right)^2 = c^2(T_i - t)^2 \tag{9}$$

with $i =$ B or S. Formal differentiation of (9) gives:

$$2\varrho_i \frac{\partial \varrho_i}{\partial p} = 2\vec{\varrho}_i \frac{\partial \vec{r}(t)}{\partial p} \tag{10}$$

or

$$2\varrho_i \frac{\partial \varrho_i}{\partial p} = 2c^2(T_i - t)\left(-\frac{\partial t}{\partial p}\right) \tag{11}$$

where

$$\frac{\partial \vec{r}(t)}{\partial p} = \dot{\vec{r}}(t)\frac{\partial t}{\partial p} + \left.\frac{\partial \vec{r}(t)}{\partial p}\right|_t \tag{12}$$

Using (10), (11) and (12) we have:

$$\frac{\partial \varrho_i}{\partial p} = \left(\frac{\frac{\vec{\varrho}_i}{\varrho_i}}{1 + \frac{\vec{\varrho}_i}{\varrho_i}\frac{\dot{\vec{r}}(t)}{c}}\right)\left.\frac{\partial \vec{r}}{\partial p}\right|_t \tag{13}$$

and finally:

$$\frac{\partial d}{\partial p} = \left[\frac{\frac{\vec{\varrho}_B}{\varrho_B}}{1 + \frac{\vec{\varrho}_B}{\varrho_B}\frac{\dot{\vec{r}}(t)}{c}} - \frac{\frac{\vec{\varrho}_S}{\varrho_S}}{1 + \frac{\vec{\varrho}_S}{\varrho_S}\frac{\dot{\vec{r}}(t)}{c}}\right]\left.\frac{\partial \vec{r}}{\partial p}\right|_t \tag{14}$$

where $\left(\frac{\partial \vec{r}}{\partial p}\right)_t$ is taken from the integration of variational equations.

5. Results

Using the TOP-COGEOS software package (**T**orun **O**rbit **P**rocessor) developed at the Institute of Astronomy of the Nicholas Copernicus University in Toruń (Drożyner, 1995), one 12 days orbital arc was successfully processed with orbital RMS fit of 3.45 meters. The (O-C) residuals are shown in Figure 1.

The 1σ errors of the dynamical state of the Eutelsat-F2 satellite are (in meters and m/sec):

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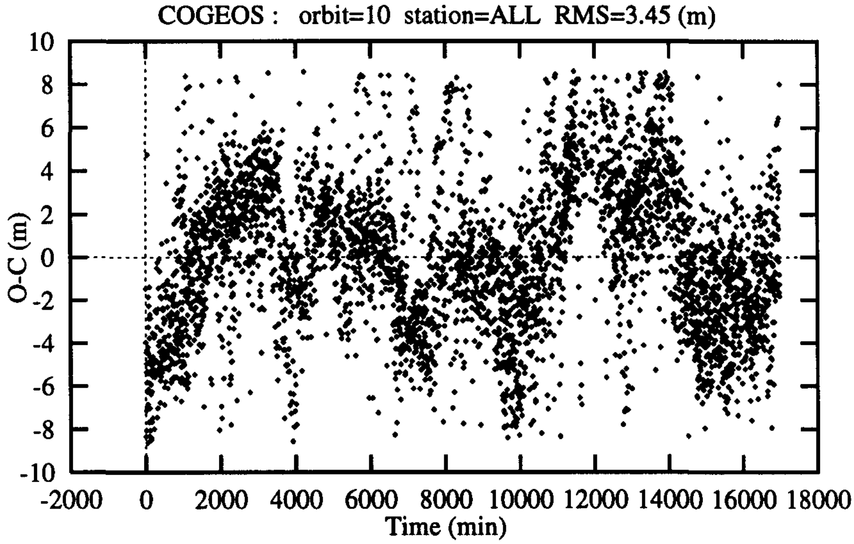

Figure 1. Residuals (O-C) in meters for 12 days orbital arc of the Eutelsat-2 satellite.

$$\sigma(\vec{r}) = (7.12, 4.56, 9.48)$$
$$\sigma(\dot{\vec{r}}) = (0.38, 0.42, 0.38) \times 10^{-3}$$

and 0.005 for scaling factor of radiative force.

6. Conclusions

A closed formulation for computing the geostationary satellite orbit has been given. Main conclusions can be formulated as follows. It is possible to use the COGEOS 4^{th} Campaign data for orbit determination on the level of a few meters of orbital fit. It is possible to determine the constant biases for each pair of stations. These biases are below 1 μsec for the European COGEOS network.

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