COMPUTATION OF PRECISE STATION COORDINATES USING LASER RANGING

H Hauck*

Frankfurt am Main

Mitteilung aus dem Institut für Angewandte Geodäsie
Frankfurt am Main

*member of the German "Forschungsgruppe Satellitengeodäsie"

Laser data of high quality obtained by the European laser stations were evaluated by the Short-Arc and a 15-days Long-Arc technique, based on the Texas University orbit processor program UTOPIA. The Long-Arc technique provided systematic patterns in the orbital residuals which lead to a mean observational error of $\pm$ 6.8 cm, while the Short-Arc residuals looked rather randomly distributed. Here the mean observational error is $\pm$ 1.9 cm. Though completely different methods were applied it turned out that the lenghts of the baselines between the stations show a good agreement.

1. Introduction

The satellite LAGEOS plays an important role in geodesy. The stability of the orbit enables investigations on the definition of a global reference system (for the station coordinates) or on the computation of earth rotation parameters.

The orbit can be predicted for a long time and thereby fit to the laser ranges observed by laser stations around the earth. However, the increase in the length of the arc produces an increase in the size of the model errors. Own numerical experiments based on the MERIT data show that the orbit residuals demonstrate a systematic behaviour at the decimeter level, which could be effected by uncertainties in the model or the data.

Over the last years laser observations to LAGEOS have improved significantly. The evaluation of the collocation experiment between the stationary NASA Laser MOBLAS 7 and the mobile Laser of IfAG MTLRS-1 in May - June 1985 at Greenbelt/USA provided an accuracy at the 2 cm level between both systems. These results were obtained using a Short-Arc method which evaluated not only systematic range or epoch biases but also the eccentricity vector between both laser systems very accurately. For this reason the Short-Arc method was extended to investigate a regionally distributed laser network, in the following the network of the European tracking stations.

2. Evaluation techniques

The evaluation of the laser data to be discussed here is based on two procedures:

The first procedure is a Short-Arc technique in which in one adjustment process the station coordinates and at the same time corrections for the simultaneously observed parts of an arc are computed, each arc considered independent from the other arcs. For each simultaneously observed arc four corrections are estimated by a least square adjustment:

Δr in radial direction
Δu in along track direction
Δi in the direction of inclination
$\Delta \Omega$ in the direction of the ascending node

Fig. 1 gives a schematic overview on the estimating procedure.

This method was successfully applied for the evaluation on the collocation experiments at the Goddard Optical Ranging Facility (GORF) at the NASA Goddard Space Flight Center near Washington D.C. (1985), WETTZELL F.R. Germany (1984/85), and MATERA in Italy (1986). Especially the eccentricity vector between the collocating systems could be adjusted with high accuracy. For the MATERA collocation the agreement between the surveyed and computed length of the eccentricity vector was better than 1 cm.

Proceedings of the Second International Symposium on Spacecraft Flight Dynamics, Darmstadt, FR Germany, 20–23 October 1986 (ESA SP-255, Dec. 1986)

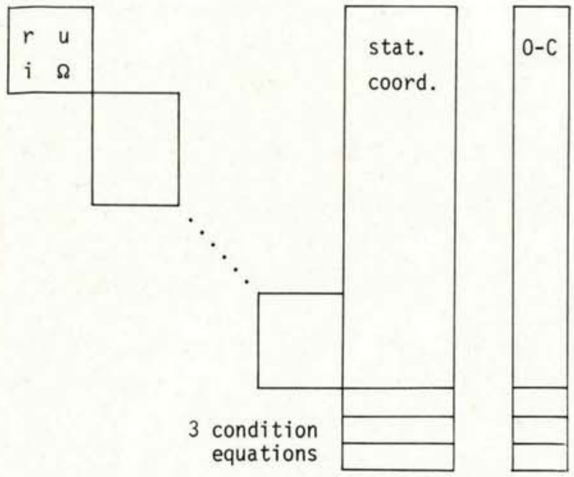

Figure 1: The Short-Arc design matrix

The a-priori station coordinates were taken from a global solution obtained from the MERIT data. Only passes simultaneously observed by at least two stations were recognized.

The second technique is based on a sequence of 15-days arcs. In general as a first step a 60-days LAGEOS arc is adjusted holding the set of very accurate a-priori station coordinates fixed to get the state vector x_o at the beginning of the arc and the best value for the empirical along track acceleration c_D.

In a second step the program UTOPIA predicts four 15-days arcs based on the state vector x_o and c_D and writes out the residuals O - C and the partials with respect to the parameters to be adjusted. Then a program system developed at IfAG carries out the final adjustment providing

a 60-days global solution of station coordinates, four state vectors, each defining a 15-days arc

and optionally

5-days mean polar motion values,

5-days mean values for the change of the length of day,

15-days values for the empirical along track acceleration and for the solar radiation coefficient, and

5-days mean values for c(2,1) and s(2,1)

In general one adjustment is not sufficient. Therefore an iteration process must be started with the improved parameters as inputs for UTOPIA which provides new residuals and partials for a further adjustment. The iteration process stops if the improvements of the station coordinates reach the sub-millimeter level. In order to get a station solution based on observations over a long time period a program for a Helmert transformation was developed which transforms several independently computed 60-days station solutions upon each other recognizing their covariances. This program also works out the significance of time dependent motions within the station network.

For the computations presented later the physical and fundamental parameters recommended in the MERIT standards (MERIT standards, 1983) were used with the following exceptions:

1. 1950.0 instead of 2000.0 reference system,
2. GM = 3.98600440 E+14 $m^3 s^{-2}$ instead of 3.98600448 E+14 $m^3 s^{-2}$,
3. ocean loading site displacements were not applied,
4. GEM-L2 prime gravitational field instead of GEM-L2,
5. no relativistic effects were applied.

The scale for the distances was based on the speed of light given by 299 792 458.0 m/sec. On the other hand GM will influence the scale due to the third Keplerian law. The value for GM mentioned above fits best to the given speed of light, while the value recommended in the MERIT standards turned out to be too big.

3. The definition of the terrestrial coordinate system

It is intended to define a terrestrial coordinate system which is very close to the CIO-system. This is realized by

1. interpolating the polar motion values x_p and y_p from BIH without adjusting them (3-1)

or

2. adjusting 5-days polar motion values x_p and y_p using partials with respect to x_p and y_p at positions x_p and y_p interpolated from the BIH-table and fullfilling the two conditions

$$\Sigma\delta x_{p_i} = 0 \qquad (3\text{-}2)$$

$$\Sigma\delta y_{p_i} = 0$$

where δx_p and δy_p are the adjusted displacements from the a-priori BIH-values:

In both cases the freedom of rotation around the z-axis must be satisfied, here by the condition

$$\Sigma\delta\lambda_i = 0 \qquad (3\text{-}3)$$

Under the assumption that the a-priori coordinates of the tracking stations are sufficiently accurate then another definition of a coordinate system proposed by (Bender and Goad, 1978) can be applied. They recommended to put three conditions on the displacements $\Delta\varphi$ and $\Delta\lambda$ from the chosen a-priori station coordinates:

$$\Sigma \Delta\lambda_i \sin\varphi_i \cos\lambda_i - \Delta\varphi_i \sin\lambda_i = 0$$
$$\Sigma \Delta\lambda_i \sin\varphi_i \sin\lambda_i + \Delta\varphi_i \cos\lambda_i = 0 \quad (3\text{-}4)$$
$$\Sigma \Delta\lambda_i \cos\varphi_i = 0$$

These conditions are derived from the requirement that the sum of the squares of the horizontal displacements should be a minimum.

If the a-priori station coordinates are given in the CIO-system and using (3-4) then the adjusted polar motion values are expected to be close to the BIH-values.

The definitions above also can be used if the terrestrial system is connected to a celestial system defined by extragalactic radio sources, in this case the computations are based on the polar motion values of IRIS.

It can not be excluded that the restrictions (3-2) to (3-4) introduced in the adjustment procedure as additional equations have some influence on the inner structure of the station network which should be dependent only upon the observations. The influence can be measured by the size of the Lagrangian multipliers of these equations: the bigger the Lagrangian multipliers the bigger is the impact on the functional model.

In /4/ it could be shown that the restrictions (3-2) to (3-4) have no influence on the inner structure of the global network, they do not disturb the length of the baselines.

4. Results

From 18. September to the 17. October 1985 the European laser stations provided a lot of laser data of high quality. Besides the fixed stations the Dutch mobile system MTLRS-2 was working at that time at an uphill place at the Monte Generoso. This system provided data of excellent quantity and quality.

Many passes were observed simultaneously, so that the opportunity was good not only to compute baselines between the European laser stations, but also to improve the functional model of evaluation.

Station	Stat. no.	Number of normalpoints
Matera	7939	89
Wettzell	7834	571
Zimmerwald	7810	353
RGO	7840	333
Monte Generoso	7590	836
Grasse	7835	537
Graz	7839	186
Potsdam	1181	33
GORF	7105	278
Quincy	7109	641
Maui	7210	244
Arequipa	7907	260
Mounment Peak	7110	203
Mazatlan	7122	398
Fort Davis	7086	87
Huahine	7121	10

Table 1: A summary of the laser data gained between day 261 and 291 in 1985

Besides the data from European stations also observations from other stations around the world were used (table 1).

Both techniques i.e. the Short-Arc and the Long-Arc method described in section 2 were applied to the mentioned data set.

However in the 15-days technique only two arcs were adjusted because of the restricted time span of the laser data.

In this technique the polar motion values were interpolated from the BIH-table, but not adjusted. To prevent the terrestrial system from rotating around the z-axis it was required to fullfill condition (3-3). Fig. 2 may explain the long Arc procedure schematically.

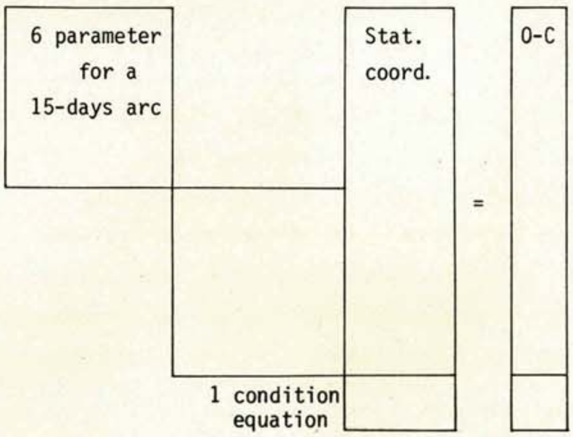

Figure 2: The 15-days arc design matrix

Table 2 shows the geodetic coordinates referred to a global ellipsoid specified by the mean radius of 6378137.0 m and the flattening of 298.257. The coordinates obtained by the Short-Arc method were transformed to the global Long-Arc solution by a Helmert-transformation.

station	height(m)	longitude	latitude
SA 7590	+1649.535	+9.01775432	+45.92755045
LA 7590	+1649.5539	+9.01775439	+45.92755014
7834	+661.173	+12.87809355	+49.14493720
7834	+661.2283	+12.87809369	+49.14493652
7835	+1322.849	+6.92111990	+43.75468888
7835	+1322.8400	+6.92111949	+43.75468914
7839	+539.389	+15.49335729	+47.06713279
7839	+539.3115	+15.49335648	+47.06713352
7840	+75.383	+0.33612087	+50.86737785
7840	+75.3731	+0.33612117	+50.86737808
7939	+535.822	+16.70468277	+40.64882974
7939	+535.8433	+16.70468343	+40.64882952

Table 2: The coordinates of the European stations obtained from the Long-Arc technique (LA) and from the Short-Arc technique (SA) after a Helmert transformation

A good agreement was found between the baselines obtained by both methods (table 3).

point 1	point 2	difference (cm) SA - LA
7590	7834	0.4
7590	7835	2.0
7590	7839	2.2
7590	7840	-5.7
7590	7939	-5.5
7834	7835	2.4
7834	7839	15.0
7834	7840	-5.5
7834	7939	-0.8
7835	7839	-1.4
7835	7840	0.5
7835	7939	-13.5
7839	7840	6.4
7839	7939	-3.7
7840	7939	-11.6

Table 3: The differences in the chord lengths based on the Short-arc-(SA) and the Long-arc-(LA) technique

It is remarkable that peaks in the baseline differences can be referred to stations which provided less data (7839, 7939). Though the results look rather good there is an important difference in both techniques. The Long-Arc technique, due to model errors, show a systematic behaviour of the orbital residuals of the ranges leading to a mean observation error of $\pm$ 6.8 cm, while the Short-Arc residuals are nearly randomly distributed with a mean observational error of $\pm$ 1.9 cm.

4. Conclusions

The short-arc and a 15-days arc technique provided baselines which in general agree better than 10 cm. The Short-arc technique fits the orbit better to the observed ranges, but the so adjusted orbits can only be realistic if the laser data are sufficiently accurate.

5. References

/1/ Bender, P., Goad, C.: The Use of Artificial Satellites for Geodesy and Geodynamics, Vol. 2, pp. 145-161, 1979

/2/ Cui, C.: Ueberpruefung und Datenkomprimierung (Normalpunkte) von Lageentfernungsmessungen nach Satelliten.
Veroeffentlichung der Bayerischen Kommission fuer die Intern. Erdmessung, Heft 45, 1984

/3/ Hauck, H., Ehlert, D., Lelgemann, D.: Definition of Reference Frames and Computation of Station Coordinates and Earth Rotation Parameters from MERIT Laser Ranging Observations, Proceedings of the International Conference on Earth Rotation and the terrestrial Reference Frame, Volume 2

/4/ Hauck, H.: A Definition of the Terrestrial Coordinate System and its Influence on the Inner Structure of the Network, Institut fuer Angewandte Geodaesie, Frankfurt, in preparation

/5/ Schutz, B., Tapley, B.: UTOPIA, University of Texas Orbit Processor Departement of Aerospace Engineering and Engineering Mechanics