TECHNISCHE HOGESCHOOL DELFT

LUCHTVAART- EN RUIMTEVAARTTECHNIEK

Memorandum M-409

SOME RESULTS OF NUMERICAL EXPERIMENTS ON THE COMPUTATION OF THE KOOTWIJK AND WETTZELL SATELLITE LASER RANGING STATION COORDINATES

by

K.F. Wakker

B.A.C. Ambrosius

Delft - The Netherlands

September 1981

SOME RESULTS OF NUMERICAL EXPERIMENTS ON THE COMPUTATION OF THE KOOTWIJK AND WETTZELL SATELLITE LASER RANGING STATION COORDINATES

K.F. Wakker and B.A.C. Ambrosius
Delft University of Technology
Department of Aerospace Engineering
Kluyverweg 1, Delft, The Netherlands

Introduction

In this paper some results are presented on the computation of the coordinates of two European satellite laser ranging stations: Kootwijk (station number 7833) and Wettzell (7834). These results were obtained within a study, described extensively in Ref. 1, which aimed at getting a physical insight in how the spatial, temporal and geographical distribution of laser ranging data, and the adoption of different perturbation models affect the orbital and parameter solution. For that study a limited number of carefully selected data-arcs had been formed from laser data of LAGEOS, STARLETTE and GEOS-3. These data had been acquired within the period July-October 1978 during 504 satellite passes over Kootwijk, Wettzell and ten other laser stations operated by NASA, SAO and CNES.

A summary of the data-arcs that were used to compute the station coordinates is presented in Table 1. For each arc the following quantities are listed: the arc identification used in this paper, the satellite involved, the start- and stop-time of the arc, the arc-length, the number of stations contributing to the observations of that arc, the number of satellite passes and the total number of observations used in the solution. The distribution of the passes over the groundstations is listed in Table 2. The arcs G1M and G2M refer to modifications of the arcs G1 and G2 in which all observations from six stations were deleted, leaving observations acquired by only four stations. This experiment was done to investigate the effects of a bad orbital coverage on the parameter solution.

The "solve-for" parameters in the computation process were the satellite's state-vector at epoch, its solar reflectivity, the drag coefficient (only for STARLETTE and GEOS-3), for LAGEOS an unmodeled along-track acceleration, a San Fernando range bias and the Kootwijk and Wettzell station coordinates.

Submitted to the 4th meeting of the LAGEOS Working Group, Goddard Space Flight Center, Greenbelt, September 1981.

The applied computation model is described in detail in Ref. 1. Here, only those aspects which are important to judge the results presented in this paper will be recalled. The coordinates of all tracking stations, except for Kootwijk and Wettzell, were held fixed at their values in the so-called Modified New Orleans (MNO) set of coordinates (Ref. 2). This is a dynamical GSFC station coordinate solution, based primarily upon laser tracking data of GEOS-3, augmented by some STARLETTE and LAGEOS data. The accuracy of these station coordinates is believed to be about 0.5 m. To model the earth's gravitational field both the GEM-9 and GEM-10B models were used. For LAGEOS also a truncated GEM-9 model, including terms up to degree and order 20 has been applied. This model is indicated as GEM-9(20). With the purpose to improve the along-track position computation of GEOS-3, for that satellite also a modified GEM-10B model was used, indicated in this paper by GEM-10BM. In this model some relevant geopotential coefficients have been assigned the values recommended in Ref. 3. For all satellites, orbit perturbations due to solar and lunar attraction, direct solar radiation pressure and solid earth tides were accounted for. For STARLETTE and GEOS-3 also atmospheric drag perturbations were taken into account. Though in Ref. 1 also GEOS-3 computations are discussed in which the concept of multiple drag coefficients has been applied, all results presented in this paper have been obtained by considering the drag coefficient, and the along-track acceleration for LAGEOS, as time-independent during each arc.

Many different computer runs have been made,each run being different in terms of perturbation models applied, observations processed or the number of adjusted parameters. Some results of these computations, concerning primarily the orbital accuracy, are discussed in Ref. 1. In this paper only the solutions obtained for the Kootwijk and Wettzell coordinates are presented. For Wettzell, four single-arc solutions have been generated. For these cases, arcs were used that did not contain Kootwijk observations, or for which the Kootwijk measurements were deliberately left out. Simultaneous Kootwijk and Wettzell two-arc coordinate solutions were obtained for each satellite.

Results

Table 3 shows a summary of the root-mean-square values of the laser range residuals for the single-arc and two-arc solutions. For the LAGEOS arc L2 the orbital fit obviously is insensitive to a change from GEM-9 to GEM-10B or GEM-9(20). For the STARLETTE arc S1 a significant improvement of the orbital fit over the groundstations was obtained when using GEM-10B instead of GEM-9. For that reason the two-arc STARLETTE solution is based on GEM-10B. The best orbital fit for GEOS-3 was obtained with GEM-10BM.

Tables 4 and 5 present the solutions for the geocentric coordinates of Kootwijk and Wettzell within the reference frame defined by the MNO set of coordinates. The formal standard deviation of the solution, being a result of the propagation of the measurement noise, is less than 7 cm. These values are not listed as they do not represent realistic estimates of the real accuracy of the solutions. From Table 4 it may be concluded that the LAGEOS solution for the Wettzell coordinates is, just as the quality of the orbital fit, hardly affected by the selection of the gravity model. For STARLETTE, in its much lower orbit, the single-arc coordinate solution for Wettzell varies some meters when replacing GEM-9 by GEM-10B. However, this must partly be the result of the relatively weak orbital solutions for this satellite, as the two-arc coordinate solution and the single-arc solution, both applying the GEM-10B model, also differ up to 0.4 m in the coordinates. Also for GEOS-3, a change of the gravity model leads to changes of a few meters in the coordinates. Assuming that the LAGEOS L1 + L2 solution is the most accurate one, it is interesting to note that the best results from the two-arc GEOS-3 solution for the Wettzell coordinates are obtained when applying GEM-10B. The GEM-10BM model does not improve the results. The G1M + G2M solution differs relatively little from the G1 + G2 solution with GEM-9, indicating that, for these arcs and for this accuracy level, the effect of decreasing the number of tracking stations is relatively small. For Kootwijk, Table 5 shows a large discrepancy of up to 2.9 m in the individual coordinates between the LAGEOS and STARLETTE solutions. The GEOS-3 solutions with GEM-10B and GEM-10BM differ little and more closely approximate the LAGEOS solution than the GEOS-3 solution with GEM-9 does.

For all Wettzell and Kootwijk coordinate solutions Table 6 presents the shift in the computed latitude, ϕ, longitude, Λ, and height, h, relative to the MNO values. Obviously, the major difference with the MNO solution is a shift of Wettzell of about 17 m to the east. This has already been reported in Ref. 4. Comparing the LAGEOS and STARLETTE two-arc solutions and the GEOS-3 two-arc solution with GEM-10B it is found that for Wettzell the shifts in the individual position components agree to within 1.4 m. For Kootwijk the internal consistency is worse due to a relatively bad STARLETTE solution which differs up to 3.8 m in the individual components from the LAGEOS solution.

In Table 7 the results for the Kootwijk-Wettzell interstation baseline are presented. From the GEOS-3 results the one with GEM-9 most closely approximates the LAGEOS solution. The mutual differences between this GEOS-3 solution and the STARLETTE and LAGEOS solutions is less than 0.5 m. Unexpectedly, the GEOS-3 solution with GEM-10BM deviates about 2 m from the LAGEOS and STARLETTE solutions.

Table 8, finally, shows a comparison between the two-arc LAGEOS solution for the Kootwijk-Wettzell baseline presented in this paper and a number of other recent solutions. For all solutions the deviation relative to the MNO solution is listed. The various solutions are not corrected for scale differences due to the application of different values of GM. Because of the short Kootwijk-Wettzell baseline of only 602 km these corrections will be less than 10 cm. The large errors of about 53 m in the SL-2 and SL-3 solutions are probably a result of not correcting for a time-tagging error in the data record of the Wettzell observations (Ref. 4). The other solutions differ less than 0.6 m from the LAGEOS L1 + L2 solution presented in this paper.

References

1. Wakker, K.F. and Ambrosius, B.A.C., Accurate orbit determinations from laser range observations of LAGEOS, STARLETTE and GEOS-3, paper presented at ESA Spacecraft Flight Dynamics Symposium, Darmstadt, May 1981.
2. Marsh, J.G., NASA Modified New Orleans station coordinates, priv. comm., February 1980.
3. Lerch, F.J., et al., Gravity model improvement using GEOS-3 altimetry (GEM-10A and -10B), paper presented at 1978 Spring Annual Meeting of Am. Geoph. Union, Florida,
4. Wakker, K.F. and Ambrosius, B.A.C., Estimation of the Wettzell coordinates from satellite laser ranging at Kootwijk, San Fernando and Wettzell, paper presented at the EROS Plenary Meeting, Grasse, April 1980.
5. Schlüter, W. et al., Final results of the EROS doppler observation campaign, paper presented at the 17th General Assembly of the IUGG, Canberra, December 1979.
6. Smith, D.E., SL-2 station coordinates derived from LAGEOS laser ranging, priv. comm., February 1980.

7. Smith, D.E., SL-3 station coordinates derived from LAGEOS laser ranging, paper presented at the third LAGEOS Working Group meeting, October 1980.

8. Tapley, B.D. et al., Preliminary tracking station solution based upon LAGEOS range observations, paper presented at the third LAGEOS Working Group meeting, October 1980.

9. Tapley, B.D. et al., Tracking station coordinate solution from LAGEOS range observations (LSC 80.11), paper presented at the Fall AGU meeting, December 1980.

10. Reigber, Ch., GRIM-3 baseline solutions, priv. comm., August 1981.

Table 1: Arcs selected for data analysis

Arc id.	Satellite	Start (yymmdd)	Stop (yymmdd)	Length (day)	Stations	Passes	Observations
L1	LAGEOS	780728	780805	8.1	9	44	2549
L2	LAGEOS	780812	780824	11.6	6	56	4813
S1	STARLETTE	780819	780825	6.5	9	56	2750
S2	STARLETTE	781010	781014	4.1	7	41	1914
G1	GEOS-3	780721	780728	7.1	8	59	3001
G2	GEOS-3	780814	780819	4.6	9	42	1903

Table 2: Data pass summary

Arc id.	S. Diego 7062	Greenbelt 7063	Bermuda 7067	Gr. Turk 7068	Patrick 7069	S. Fernando 7804	Kootwijk 7833	Wettzell 7834	Arequipa 9907	Mt. Hopkins 9921	Natal 9929	Orroral 9943
L1	5	2	3	–	–	–	5	2	14	1	1	11
L2	14	5	3	–	–	–	–	7	15	–	–	12
S1	6	9	4	–	–	–	3	7	17	3	4	3
S2	4	–	–	2	–	–	8	–	9	8	1	9
G1	–	2	–	–	8	5	10	4	19	–	1	10
G2	6	2	2	–	4	2	8	–	14	–	2	2
G1M	–				8		10	4	10		–	–

Table 3: Summary of the laser residual rms values in meters in the solutions for the Kootwijk and Wettzell station coordinates.

Arc id.	Model	S. Diego 7062	Greenbelt 7063	Bermuda 7067	Gr. Turk 7068	Patrick 7069	S. Fernando 7804	Kootwijk 7833	Wettzell 7834	Arequipa 9907	Mt. Hopkins 9921	Natal 9929	Orroral 9943	Overall
L2	GEM-9	0.4	0.5	0.7	-	-	-	-	0.2	1.2	-	-	1.6	0.9
L2	GEM-10B	0.4	0.5	0.7	-	-	-	-	0.2	1.2	-	-	1.5	0.9
L1	GEM-9(20)	0.4	0.2	0.6	-	-	-	0.5	0.2	1.1	0.7	1.9	1.6	1.1
L2	GEM-9(20)	0.4	0.5	0.7	-	-	-	-	0.2	1.2	-	-	1.5	0.9
S1	GEM-9	1.8	1.4	0.9	-	-	-	-	2.2	3.6	2.8	3.7	4.2	2.6
S1	GEM-10B	1.5	1.0	0.8	-	-	-	-	1.3	3.2	2.6	4.7	1.8	2.2
S1	GEM-10B	1.5	1.0	0.8	-	-	-	2.3	1.2	3.2	2.6	4.8	1.7	2.2
S2	GEM-10B	1.4	-	-	1.5	-	-	1.3	-	4.0	2.8	4.3	2.0	2.6
G1	GEM-9	-	1.6	-	-	1.7	2.7	2.0	0.9	2.9	-	0.7	3.0	2.3
G2	GEM-9	1.7	0.9	1.1	-	1.4	3.5	1.6	-	2.6	-	3.8	3.6	2.2
G1	GEM-10B	-	1.8	-	-	1.7	2.6	1.6	1.7	2.5	-	1.5	2.2	2.1
G2	GEM-10B	2.0	0.5	0.9	-	1.6	5.0	1.8	-	2.7	-	3.7	2.0	2.2
G1	GEM-10BM	-	1.6	-	-	1.5	2.5	1.4	1.0	2.9	-	1.8	1.7	2.0
G2	GEM-10BM	1.9	1.0	0.6	-	1.0	2.8	1.3	-	2.2	-	3.2	2.2	1.9
G1M	GEM-9	-	-	-	-	1.3	-	1.8	0.9	2.8	-	-	-	2.0
G2M	GEM-9	-	-	-	-	0.4	-	1.5	-	1.8	-	-	-	1.6

Table 4: Solutions for the Wettzell coordinates

Arc id.	Model	Coordinates (m)		
		X	Y	Z
L2	GEM-9	4075532.3	931777.9	4801617.9
L2	GEM-10B	32.3	77.8	17.9
L1+L2	GEM-9(20)	32.3	77.8	17.9
S1	GEM-9	34.3	72.6	19.0
S1	GEM-10B	31.8	77.4	18.0
S1+S2	GEM-10B	32.2	77.3	17.6
G1+G2	GEM-9	33.3	79.2	17.0
G1+G2	GEM-10B	32.3	76.4	18.4
G1+G2	GEM-10BM	31.4	76.5	20.6
G1M+G2M	GEM-9	33.6	80.5	17.2

Table 5: Solutions for the Kootwijk coordinates

Arc id.	Model	Coordinates (m)		
		X	Y	Z
L1+L2	GEM-9(20)	3899225.0	396739.4	5015074.1
S1+S2	GEM-10B	27.9	37.1	71.4
G1+G2	GEM-9	27.2	39.8	72.9
G1+G2	GEM-10B	25.7	38.8	74.3
G1+G2	GEM-10BM	25.6	38.9	74.4
G1M+G2M	GEM-9	27.1	39.9	73.2

Table 6: Shift in latitude, longitude and height of Wettzell and Kootwijk relative to MNO values in meters

Arc id.	Model	Wettzell			Kootwijk		
		$\Delta\phi$	$\Delta\Lambda$	Δh	$\Delta\phi$	$\Delta\Lambda$	Δh
L2	GEM-9	-1.0	17.2	2.0	-	-	-
L2	GEM-10B	-1.0	17.2	2.0	-	-	-
L1+L2	GEM-9(20)	-1.0	17.2	2.0	-0.0	1.4	0.1
S1	GEM-9	-0.9	11.6	3.3	-	-	-
S1	GEM-10B	-0.5	16.8	1.7	-	-	-
S1+S2	GEM-10B	-1.0	16.7	1.6	-3.8	-1.2	-0.3
G1+G2	GEM-9	-2.6	18.3	2.1	-2.5	1.5	0.6
G1+G2	GEM-10B	-0.5	15.8	2.2	-0.4	0.7	0.7
G1+G2	GEM-10BM	1.6	16.1	3.3	-0.2	0.8	0.7
G1M+G2M	GEM-9	-2.9	19.5	2.6	-2.2	1.7	0.8

Table 7: Comparison of the solutions for the Kootwijk-Wettzell interstation baseline

Arc id.	Model	Baseline (m)
L1+L2	GEM-9(20)	602423.3
S1+S2	GEM-10B	23.2
G1+G2	GEM-9	23.8
G1+G2	GEM-10B	22.3
G1+G2	GEM-10BM	21.4
G1M+G2M	GEM-9	25.0

Table 8: Survey of various published solutions for the Kootwijk-Wettzell baseline. All results are expressed as deviations from the MNO baseline value and are not corrected for scale differences

Solution	Baseline difference (m)
L1+L2, GEM-9(20), this paper	13.3
Wakker, GEM-9, Ref. 4	13.4
Schlüter, EROS doppler, Ref. 5	13.0
Smith, SL-2, Ref. 6	-39.3
Smith, SL-3, Ref. 7	-40.2
Tapley, Ref. 8	13.9
Tapley, LSC-80.11, Ref. 9	12.8
Reigber, GRIM-3 , Ref. 10	13.1