DETERMINATION OF EARTH ROTATION AND STATION COORDINATES FROM LAGEOS DATA

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ABSTRACT A package of computer programs for the analysis of satellite laser ranging data has been written at the Royal Greenwich Observatory. The methods used are described, and the Earth rotation parameters and station coordinates derived from the MERIT Lageos data are given, with comparisons with other determinations. The uncertainty of the absolute value of the z-coordinate of the stations is discussed, and a method of short-arc analysis for determining baselines is described.

1. INTRODUCTION

The operation of a satellite laser ranging station was commenced at the Royal Greenwich Observatory in 1983 October. In order that the laser data from this and other stations can be analysed in the UK a package of computer programs, SATAN (for satellite analysis) has been developed at RGO (Sinclair and Appleby, 1986). The package includes programs for processing the laser data (eg. forming normal points) and for the generation of the orbit of the satellite by numerical integration (using a Gauss-Jackson 8th order method) and for parameter estimation. Any gravity field model can be used, evaluated to any degree and order. For low satellites, drag is calculated using Jacchia's (1972) atmospheric model, which is evaluated by an efficient procedure (Oliver, 1982). For Lageos an empirical acceleration is used instead of a drag term, and the force model used is that recommended by project MERIT Standards (1983).

In this paper we describe the results that have been obtained from the analysis of the Lageos laser ranging data from the MERIT campaign (1983 September to 1984 October inclusive). The data used were the normal points for Lageos formed by the Center for Space Research (CSR), University of Texas. The results for station coordinates and Earth rotation parameters (ERPs) are compared with other determinations from laser data, and are in good agreement, and the ERPs also agree well with the independent set determined from the IRIS VLBI data. The largest uncertainty of the station coordinates is the absolute value of the z-coordinate, and we investigate the variation of determinations of this

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quantity. This does not affect the relative accuracy of the station coordinates, which by comparison of determinations by various analysis groups from the same Lageos data set appears to be about 3.5 cm. In order to test this accuracy we use a short-arc method of determining baselines between four European stations, so that the determination is virtually independent of the force model used for Lageos. We find good agreement with the baselines derived from station coordinates determined from the usual long-arc method.

2. METHOD OF SOLUTION

The GEML2 gravity field model used for Lageos was derived using the BIH series of polar motion (Lerch et al, 1985), and the coefficients C_{21} and S_{21} have been adjusted to correspond to the offset of the axis of maximum moment of inertia of the Earth from the terrestrial pole as implied by the BIH series (MERIT Standards, 1983, p.A10-1). Hence the terrestrial pole of the station coordinates used in conjunction with GEML2 should be close to the BIH pole. A constraint must be imposed on a simultaneous solution for station coordinates and ERPs for determinacy, and this should be chosen in such a way that the pole is close to the BIH pole. We have done this by an iterative method, in which the station coordinates and ERPs are not solved-for simultaneously. First we adopt the BIH ERPs, and solve for the parameters of the orbit of Lageos and the station coordinates. Hence the station coordinates adopt a pole close to the BIH pole. Then we fix the station coordinates, and solve for the orbit parameters again and the ERPs. Finally we fix these ERPs, and solve for the orbit parameters and the station coordinates again.

The orbit parameters that were solved-for are the initial position and velocity of Lageos, the empirical acceleration and its rate of change, and the solar radiation pressure coefficient. These parameters were determined from arcs of the orbit of 36 days throughout the 14 months of the MERIT data. Successive arcs had a 6-day overlap. A single set of station coordinates was determined from the whole 14 months' data, using the Helmert-Wolf technique (Cross, 1982) for the combined solution for the local parameters affecting each individual arc and for the global parameters affecting all of the arcs. The longitude of one station (7907, Arequipa) was fixed to make the solution determinate.

In the solution for orbit parameters and ERPs, all the parameters are local, so the normal least-squares method was used. The ERPs were determined at equally spaced points 3 days apart. The value of UT1-UTC at the start of the first arc was taken from BIH, but thereafter the values of UT1-UTC that have to be fixed for determinacy in each arc were taken from the overlap with the previous arc. Hence the series of UT1-UTC is determined purely by the Lageos data and the force model used, and so can be expected to drift from the real values, due to inadequacies of the force model affecting the node of the orbit. Hence comparison of our UT1 series with a series determined from an absolute technique such as VLBI give a means of determining the inadequacies of the force model.

3. COMPARISON OF RGO SOLUTION WITH OTHER SOLUTIONS

The RGO series of ERPs has been compared with determinations by other groups (CSR, GSFC, DGFI) from the same MERIT data set, and with the completely independent IRIS VLBI determination. Apart from constant offsets, due to the use of different terrestrial poles, the coordinates of the pole agree to about 2 milli-arcsec RMS. (The formal standard errors of the values of the coordinates of the pole in the RGO solution are about 1 milli-arcsec.)

The upper plot in Figure 1 gives the comparison of the RGO series of UT1R with the series determined by the IRIS VLBI network, and as expected they drift apart. The drift is about 3.8 millisec in 14 months, and there are also pseudo-periodic variations. The spectral analysis in the lower plot shows that there is evidence for periodic terms of periods 13.8 days, 152 days and about 300 days. These are probably tidal terms affecting the node of the orbit which are not modelled sufficiently accurately. With the slope and these perodic terms removed, the RMS difference from IRIS is 0.27 millisec. The formal standard errors of the RGO solution for UT1R are about 0.1 millisec.

The station coordinate set determined in the RGO solution has been compared with other sets derived from the MERIT Lageos data, by CSR (Tapley et al, 1985), GSFC (Smith et al, 1985) and by DGFI (Reigber et al, 1985). A best-fitting 7-parameter transformaton (offsets, rotations and scale) is determined in each comparison, and the RMS difference of the coordinates after the transformation is obtained. However the determinations of the coordinates of the individual stations are not all of the same accuracy, due to the differing amounts, distribution and accuracy of their range data. Hence the determination of the transformations has been limited to the 15 stations for which there are more than 1000 normal points in the MERIT data set. Even among these 15 stations there are some disparate determinations of station coordinates, after the transformations have been applied. In the RGO solution the coordinates of stations 7112, 7121, 7907 and 7939 differ by 10 to 15 cm from the determinations by other analysis groups and those by GSFC for the stations 7105, 7109 and 7112 differ by about 10 cm. Apart from these differences the RMS differences of the coordinates of the remaining stations after the 7-parameter transformation are typically 3.5 cm. In the transformation the offsets of the coordinate systems in x and y, and the scale difference are virtually insignificant. If zero differences are imposed and only a 4-parameter transformation is solved for then the RMS differences of the station coordinates rise to about 4.5 cm. Of these 4 parameters the rotations are significant, as is to be expected due to the different terrestrial poles and origins of longitude used. The offsets in the z-direction are also significant, although theoretically these should be zero, since the origin of the station coordinates should be the centre of mass of the Earth. Relative to the coordinate frame of the CSR station coordinates these offsets of the z-coordinate are about 11 cm for DGFI, 15 cm for GSFC and 20 cm for RGO.

These offsets of the z-coordinates are due in part to the way in which a constraint is applied to the solution for station coordinates and ERPs. Some analysis groups fix the longitude of one station and the latitudes of two stations, and this inevitably puts a constraint on the z-coordinates. In the iterative method of solution used by RGO no such constraint is made, and it is found that although the relative z coordinates are well determined, the absolute value is not well determined. This can be seen in Figure 2, in which a solution has been made from each month's data for the orbit parameters, the ERPs, and for an overall shift in z of the RGO coordinate set. Large variations of z of up to 27 cm occur. This is possibly due to the fairly high correlations of about 0.88 that exist between the eccentricity and apse of the orbit and the shift in z. The cause of this correlation is probably the almost polar orbit of Lageos, which is such that a displacement of the coordinate system in the z direction is similar to moving the centre of mass of the Earth within the orbit plane, and this is similar in effect to a change of eccentricity and apse. The launch of Lageos II in a lower inclination orbit made solve this problem.

In order to investigate further the relative accuracy of the station coordinates a method of short-arc orbital analysis has been used. This method used short arcs of the orbit of up to 30 minutes which have been tracked simultaneously by 3 or more stations. First a long-arc orbit is generated from one month's data, and for each short arc a solution is made for along-track and radial corrections to this orbit, as well as corrections to the relative station coordinates from the combination of many such short arcs. There is a high correlation between the radial and across-track corrections, so that both of these can not be solved-for. This short-arc method is virtually independent of the force model used for Lageos, and so provides a check on the usual long-arc analysis method. This short-arc method has been used to determine the baselines between 4 European stations using the data from each of the final 7 months of the MERIT campaign, where there were many occurrences of simultaneous tracking. From the variations of these values we deduce that the standard error of individual baseline estimates from one month's data are 1.2 to 4.0 cm, and the standard errors of the means from 7 months' data are 0.5 to 1.5 cm. In Table 1 we give the values of the same baselines calculated from the station coordinates obtained by various analysis groups from the MERIT data, together with the mean of the values from the short-arc method. These values are in good agreement with each other, and give confidence in the estimate above of 3.5 cm for the random errors of the station coordinate determinations.

Table 1. Baselines (to intersection of the telescope axes) calculated from the station coordinates obtained by various analysis groups and by the short-arc method from the MERIT Lageos data.

Stations		Baselines (metres)				
		RGO	CSR	GSFC	DGFI	Short-arc
7834-7839	30 2138 +	0.49	0.48	0.47	0.49	0.51
7834-7840	91 7333 +	1.01	1.03	1.02	1.00	1.00
7834-7939	99 0118 +	0.92	0.98	0.97	0.95	0.95
7839-7840	118 3242 +	0.74	0.76	0.74	0.76	0.75
7839-7939	71 9404 +	0.96	1.03	1.03	1.01	0.97
7840-7939	169 4490 +	0.95	1.00	0.98	0.97	0.93

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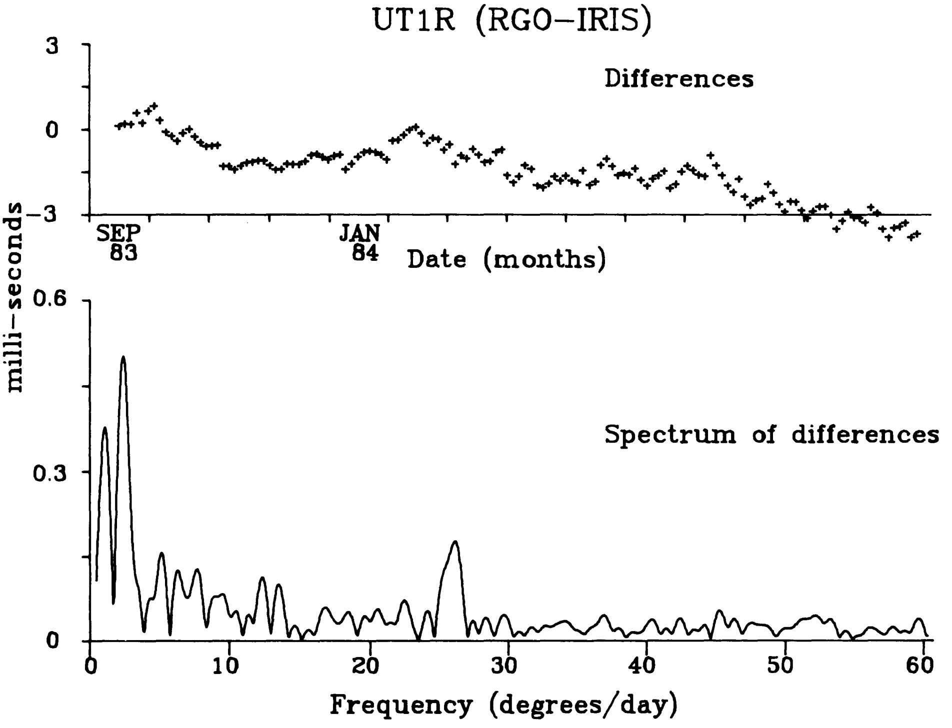

Figure 1. Comparison of RGO and IRIS series of UT1R. The spectral plot shows periods of 13.8, 152 and about 300 days.

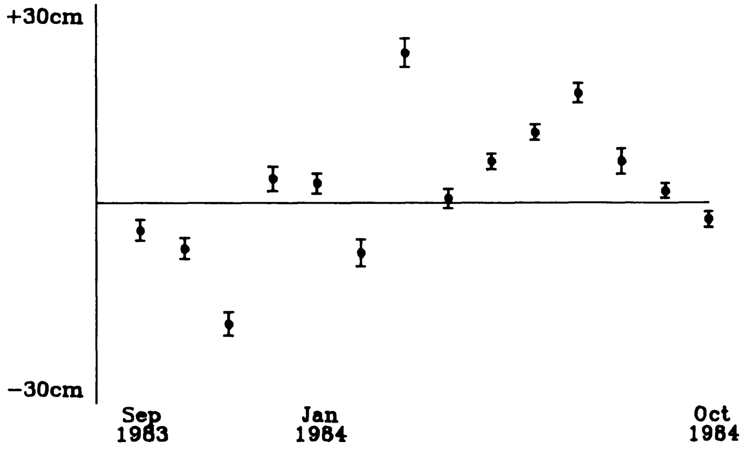

Figure 2. The variations of monthly determinations of a correction to the z-coordinate of the reference frame.

CONCLUSIONS

The coordinates of the pole determined in the RGO solution from the MERIT Lageos data set are in good agreement with other determinations from the same data set and with the IRIS VLBI determination, to about 2 milli-arcsec RMS. The RGO determination of UT1R drifts from the IRIS determination by about 3.8 millisec in 14 months, and also shows periodic differences, due to the small inadequacies of the Lageos force model. The comparison of the RGO and other station coordinate sets shows good agreement to about 3.5 cm RMS for most stations, but there are some for which the agreement is rather worse. The most significant systematic differences of the coordinate sets are their relative displacements in the z-direction. The method of constraint on the solution commonly used of fixing two latitudes will inevitably cause differences of the z-coordinate. In the RGO solution this constraint is not made, and considerable variations in the determination of the z-coordinate from month to month are found. A short-arc method has been used for determining baselines between some European stations, and the results are in good agreement with those from the station coordinate sets.

REFERENCES

Cross,P.A., 1982. Lecture notes for seminar on advanced least-squares applied to position-fixing. North East London Polytechnic.

Jacchia,L.G., 1972. In COSPAR International Reference Atmosphere, Akademie-Verlag, Berlin. 227-328

Lerch,F.J.,Klosko,S.M.,Patel,G.B.,Wagner,C.A., 1985. J.Geophys.Res., **90**, 9301-9311

Oliver,W.L., 1982. A procedure for the efficient calculation of atmospheric density. COSPAR paper II.2.8, Ottawa

Project MERIT Standards, 1983. US Naval Obs.Circ.no.167 (W.Melbourne, R.Anderle,M.Feissel,R.King,D.McCarthy,D.Smith,B.Tapley,R.Vicente)

Reigber,Ch.,Muller,H.,Schwintzer,P.,Massmann,F.H.,Pavlis,E.C., 1985. Proc.Int.Conference on Earth Rotation and Terrestrial Reference Frame. Columbus, Ohio, 88-103

Sinclair,A.T.,Appleby,G.M., 1986. SLR Technical Note no.9. Royal Greenwich Observatory

Smith,D.E.,Christodoulidis,D.C.,Torrence,M.H.,Klosko,S.M.,Dunn,P.J., 1985. Proc.Int.Conference on Earth Rotation and Terrestrial Reference Frame. Columbus, Ohio, 142-171

Tapley,B.D.,Eanes,R.J.,Schutz,B.E., 1985. Proc.Int.Conference on Earth Rotation and Terrestrial Reference Frame, Columbus, Ohio, 111-125