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4.7 ANALYSIS SOFTWARE

By

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ABSTRACT

Precise data analysis for a satellite orbit and the station coordinates requires the latest physical models of the Earth rotation, the site displacement and the satellite acceleration. The short-arc analysis software QCAR as well as the global orbit analysis software CONCERTO is developed for the Keystone data analysis. We tested two analysis methods: the global analysis for determining the coordinates in a global reference frame; and the short-arc analysis for determining the local relative coordinates for short solution interval.

Keywords: Laser ranging, Orbit determination, Station coordinates, Regional crustal deformation

1. Introduction

Up-to-date satellite laser ranging (SLR) systems, such as the Keystone project, have attained precision better than 1 cm in their regular operations. The range data is required to be processed using precise physical models. Four Keystone stations are densely located within about 100×100 km and they are operated almost under the same system configurations, the weather and the operational policies. It is expected that they will produce range data not only precisely but efficiently.

We developed the orbit analysis software CONCERTO[1][2], which enables the orbit generation/determination based on the latest physical models like the IERS Conventions[3]. Currently the C++ version of CONCERTO is operational and the physical models and the computational methods listed in Table 1 are almost compatible with the VLBI analysis procedure. The software also enables a user to configure the analysis conditions flexibly and easily.

Although global orbit determination makes it possible to link the station coordinates to a well-defined geocentric reference frame, it does not completely converge range data below the observation precision. Estimating the station coordinates usually needs at least a month's observation. There have been several attempts to obtain a regional network solution by clipping the satellite orbit into short arcs[4][5][6]. We have developed an analysis program QCAR that derives the regional relative station positions as well as some arc parameters, by using the range residuals generated by the orbit analysis software.

In this paper, we describe the strategy and some sample results of the global and the regional analysis.

2. Global Analysis

2.1 Analysis method

The laser ranging technique can be used to determine the station coordinates in a global reference frame just through the regular ranging operation. This is because geodetic satellites are densely tracked from dozens of laser stations and because their orbits can be determined by using physical force models and by adjusting some parameters. The station coordinates can be defined in the geocentric terrestrial reference frame.

A batch filtering is used in estimating the orbit at an interval of a few days to several months whereas the station coordinates are estimated every one months or longer.

The global methods have the advantage that the station coordinates can be defined in a geocentric reference frame. Although recently the force model has been getting more well-known, an orbital error due to the force model, being insufficient, is absorbed into the station coordinates. At least one months' data is needed to determine the station coordinates because we must wait until the force model error averages out.

2.2 Sample of analysis result - A set of station coordinates, SSC(CRL)97L

A set of global coordinates of laser stations was determined using the range data to Lageos-1 and Lageos-2 during 1993-1997. The orbit was chopped into two-day arcs, and six orbit elements and some acceleration coefficients such as the solar radiation pressure and the along-track force were estimated. All the station coordinates are estimated every sixty days giving a constraint of at least a few cm. The IERS Bulletin B is used for the Earth orientation without adjusting the parameters. Each solution set of the sixty-day station coordinates was fit to the ITRF94 (IERS Terrestrial Reference Frame, 1994[7]) by a seven-parameter adjustment[3]. The positions and the velocities were derived for all the stations using the five-year results. Since the time evolution of the ITRF94 is defined to be consistent with the geophysical model, NNR-NUVEL1A, our solution, SSC (CRL) 97L, is also consistent with it.

The horizontal and the vertical components of the velocity field of SSC(CRL)97L are shown in Figs. 1 and 2. Fig. 1 indicates the global plate motion, and Fig. 2 implies that no clear vertical motions were detected at the good stations. For several stations in North America and in Europe whose quality and quantity have been kept high, the three-dimensional velocities agreed with the ITRF94 within 2 mm/year.

In this way, the station coordinates of a laser station can be given in a global reference frame and the velocity can be also determined usually from a few years' ranging

Table 1 Physical models and computational methods in CONCERTO.

Method/phenomenon	Models in CONCERTO
Numerical integration	Cowell's Method (Oesterwinter, 1972)
Tidal deformation of a local site	
Solid Earth tides	IERS Standards 1992 or IERS Conventions 1996
Ocean loading	IERS Standards 1992 or IERS Conventions 1996 with Scherneck's coefficients
Polar motion effect	IERS Standards 1992 or IERS Conventions 1996
Earth rotation	
Precession	IERS Standards 1992 (=IERS Conventions 1996)
Nutation	JPL DE/LE or IERS Standards 1992 or IERS Conventions 1996
Diurnal motion and wobble	IERS Bulletin A/B available.
Geocenter	Constant or adjusted
Satellite acceleration	
Geopotential	GEM-T1,T2,T3,JGM-3 and EGM-96 available
Solid Earth tides	IERS Standards 1992 or IERS Conventions 1996
Ocean tides	IERS Standards 1992 (=IERS Conventions 1996) with CSR 3.0 model
Pole tide	IERS Standards 1992 or IERS Conventions 1996
Three body gravity	Planetary Ephemeris : JPL DE/LE 245
Solar radiation pressure	IERS Standards 1992 (=IERS Conventions 1996)
General relativity	IERS Standards 1992 (=IERS Conventions 1996)
Atmospheric drag	DTM94 density model or exponential model
Along-track acceleration	Constant or adjusted
Once-per-revolution force	Three dimensionally constant or adjusted
Tropospheric refraction	IERS Standards 1992 (=IERS Conventions 1996 =Marini and Murray, 1973)
Station bias	
Range bias	Constant or adjusted
Time bias	Constant or adjusted
Frequency bias	Constant or adjusted
Environment	Windows NT/9x with a C++ compiler, on Intel x86 or DEC Alpha CPU

data. In this special issue[8], the first solution for the Keystone stations is given and then compared with the VLBI results.

3. Regional Analysis

3.1 Analysis method

In the Keystone laser ranging network the stations are densely placed. As we can expect similar weather conditions and the common observation schedule, the network will be able to get many co-observed (=observed from more than two stations) passes. There is an alternative method to solve the station coordinates if only the relative position within a limited local region is required.

In this so-called "short-arc" analysis the satellite orbit is chopped into shorter arcs, and all or some of orbital elements as well as the station coordinates are solved for. This type of analysis can shorten the solution interval of the station coordinates, because it can remove the systematic trends due to the insufficient orbit force model. But generally it cannot refer to the geocentric terrestrial reference frame.

Among the several kinds of short-arc analysis methods we applied the single-pass method[4] in which only the co-observed passes are processed and the satellite orbit is divided into very small arcs. We developed new Java software QCAR (Quick Coordinate Analysis using Residual data) to analyze the post-fit residual data produced by CONCERTO orbit analysis. The QCAR software detects the co-observed passes from the focused laser sites and any of six orbital components, the along-track, the across-track, the radial elements and their rates, can be adjusted.

For example, the partial derivative of the observed range ρ with respect to the along-track element r_{along} can be expressed as:

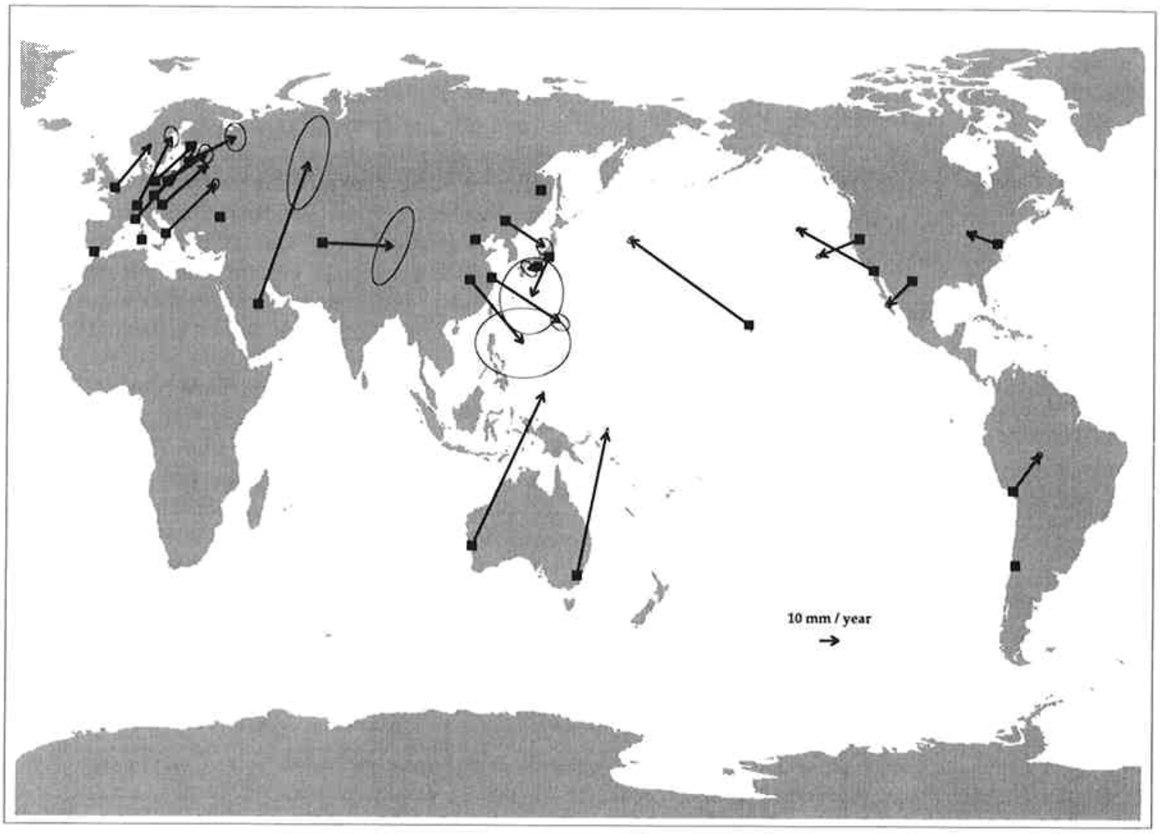

Fig. 1 Velocity field of the SSC(CRL)97L (horizontal components).

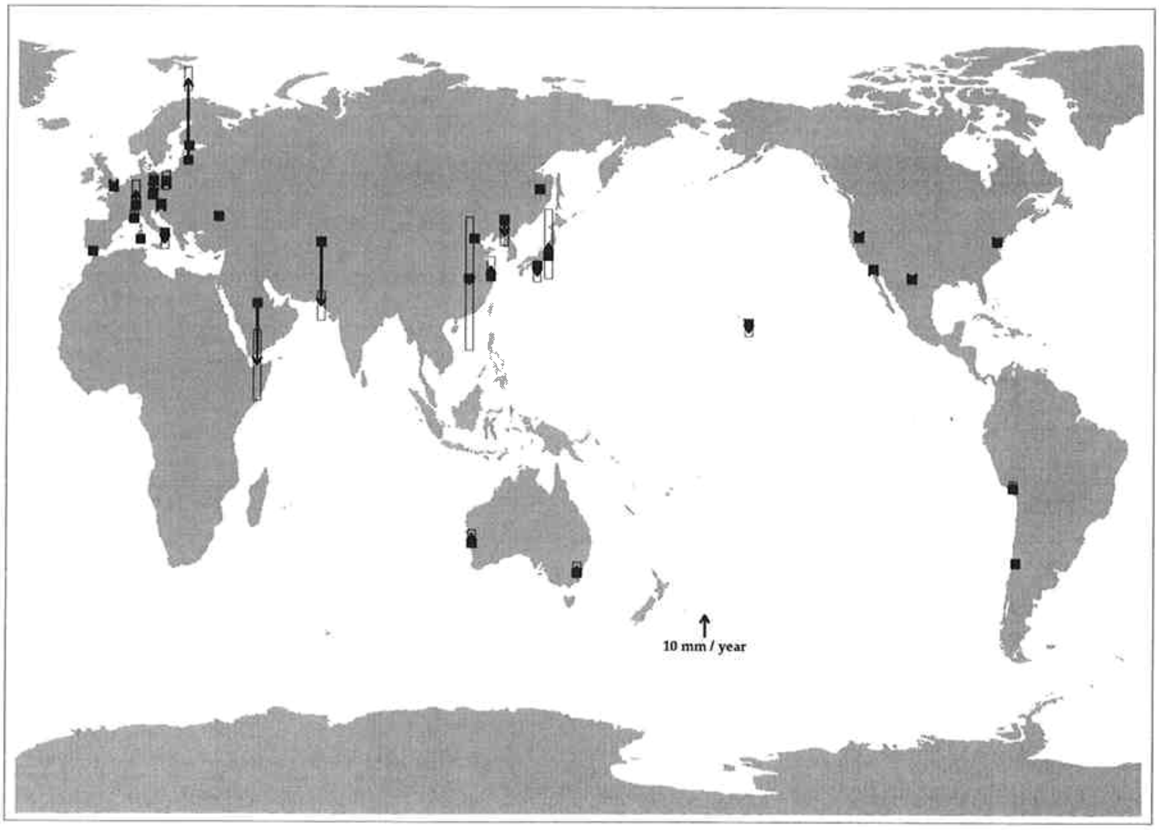

Fig. 2 Velocity field of the SSC(CRL)97L (vertical components).

$$\frac{\partial \rho}{\partial r_{along}} = \frac{\partial \rho}{\partial x}\frac{\partial x}{\partial r_{along}} = \left[\frac{(x_x - s_x)}{\rho}\ \frac{(x_y - s_y)}{\rho}\ \frac{(x_z - s_z)}{\rho}\right]\begin{bmatrix}\hat{v}_x \\ \hat{v}_y \\ \hat{v}_z\end{bmatrix}$$

where $\mathbf{x} = (x_x\, x_y\, x_z)^T$ and $\mathbf{s} = (s_x\, s_y\, s_z)^T$ are the position vectors of the satellite and the station, respectively, and $\hat{v} = (\hat{v}_x\, \hat{v}_y\, \hat{v}_z)^T$ is the normalized velocity vector of the satellite.

It uses the free network adjustment technique[9] to adjust the three-dimensional station coordinates by constraining the transference (three constraints) and rotation (three constraints) of the focused network. Under these constraints, with two sites only the baseline length is sensitive, and with more than four sites the vertical component becomes sensitive.

3.2 Sample of analysis result-European network

The five laser ranging stations in Europe, Grasse (CDP Number:7835), Potsdam (7836), Graz (7839), Herstmonceux (7840) and Wettzell (8834), are located within approximately 1,200 km baseline. This network is focused on here as a feasibility study of Keystone network analysis, although it is much larger than Keystone's 135 km baseline.

The normal-point range data sets of Lageos-1 and Lageos-2 were firstly processed by CONCERTO for the first half of 1998. Four periods --- 10 days from February 17, 11 days from March 19, 10 days from May 2, and 9 days from May 12 --- were chosen for this test because each of them includes more than 15 co-observed passes. Using the post-fit residuals and the QCAR software, we estimated the station coordinates in each of the 9-11 day periods with the six constraint conditions. For each co-observed pass two orbital parameters, the along-track and radial elements, were also adjusted. Every normal point made of more than three single-shots is evenly weighted.

The estimated positions were plotted in Figs. 3 and 4; the horizontal components are shown as baseline lengths from Herstmonceux station, and the vertical components are shown as the height from the IERS reference ellipsoid[3]. The dotted lines are from the SSC (CRL) 97L. In both components the solutions were stable within 6 mm rms. Although all the data was equally weighted, the two, Graz and Herstmonceux, whose quality is said to be

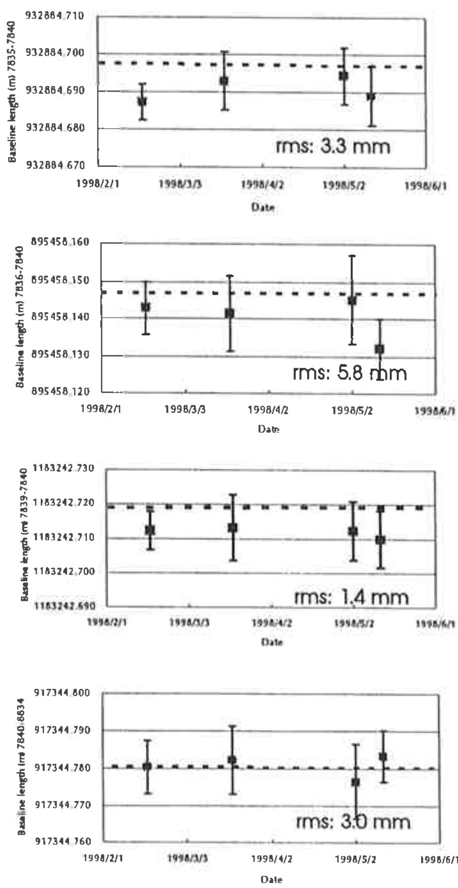

Fig. 3 Baseline length between Herstmonceux station and the others, derived from the short-arc analysis.

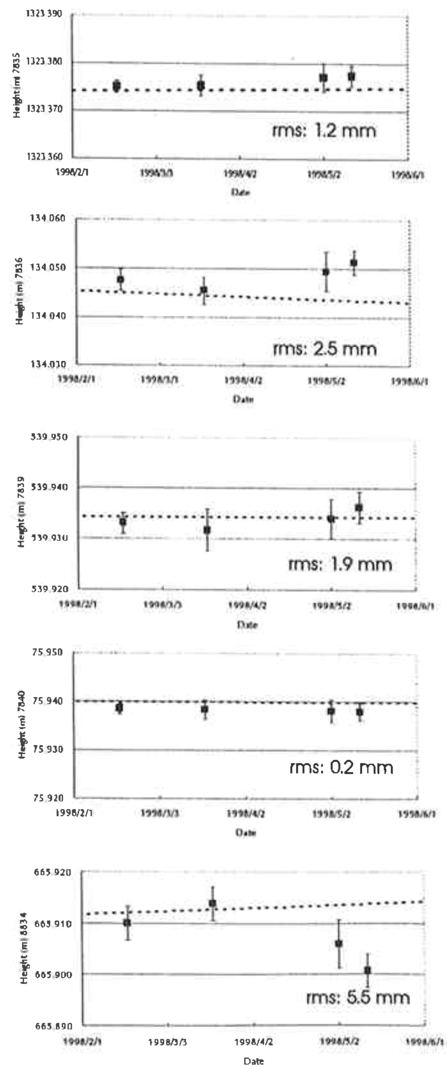

Fig. 4 Station heights derived from the short-arc analysis.

kept high, gave stable results within 2 mm rms. This type of analysis is sensitive to the biased range data since the observation error in relatively small data amounts can be absorbed in the adjustment of station coordinates.

4. Conclusion

We developed a global analysis and a regional analysis, and we plan to use both of them regularly. The global analysis will run every several months to determine the global station coordinates. Using these coordinates as the initial state, the regional analysis will be used more frequently to investigate the local crustal deformation.

To improve the precision and the time resolution, the use of other satellites will be effective. The assessment of orbit error for each satellite is needed for appropriate data weighting.

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