

3.6.2.4 Forsvarets forskningsinstitutt (FFI)

Introduction

Forsvarets forskningsinstitutt (FFI, Norwegian Defence Research Establishment) has during the last 19 years developed a software package called GEOSAT (Andersen, 1995) for the combined analysis of VLBI, GPS, SLR and other types of satellite tracking data (GLONASS, DORIS, PRARE and altimetry). The observations are combined at the observation level with a consistent model and consistent analysis strategies. The data processing is automatized except for some manual editing of the SLR observations.

In the combined analysis of VLBI, GPS and SLR observations the data are processed in arcs of 24 hours defined by the duration of the VLBI session. The result of each analyzed arc is a state vector of estimated parameter corrections and a Square Root Information Array (SRIF) containing parameter variances and correlations. The individual arc results are combined into a multi-year global solution using a Combined Square Root Information Filter and Smoother program called CSRIFS. With the CSRIFS program any parameter can either be treated as a constant or stochastic parameter between the arcs. The estimation of multi-day stochastic parameters is possible and extensively used in the analyses.

Analysis strategy

Presently, the most important stochastic parameters of the global level state vector are the following: Radio source coordinates (1d resolution) of sources with structure index 3 or 4, geocentre coordinates (3d resolution), Earth orientation parameters (1d), the C21 and S21 gravity coefficients (6d), satellite independent SLR ranging biases (15d), Solar radiation pressure scaling and empirical drag of the Lageos satellites (3d), and GPS receiver antenna eccentricity vectors (station dependent time resolution to account for instrumental changes). The reason for including the two gravity coefficients is to account for the fact that errors in the gravity field will map into the estimates of polar motion derived from satellite tracking data. In order to be consistent with VLBI, which is almost independent of gravity, these parameters must be estimated.

The main constant parameters of the global state vector are monument coordinates and velocities, GPS and/or SLR eccentricity vectors relative to the station monument if it is a colocated station, radio source coordinates, relative zenith delay between VLBI and GPS at colocated stations (to account for differences in antenna heights), VLBI antenna axis offsets, and GPS satellite transmitter phase centre z-coordinate offset and nadir-dependent variation (relative to the satellite body-fixed reference frame). The commonly adopted z-coordinates for the effective phase centre of the GPS transmitter antennas are probably wrong by 1-2 meters.

Results show that the z-coordinate, as a function of the nadir angle, can be determined to a formal precision of some centimeters (1 sigma). Using the IGS z-coordinate values will result in a scale inconsistent with SLR and VLBI by several ppb. This means that most, but not all, of the error in the GPS phase centre offset is absorbed by the estimated clock and ambiguity parameters. However, the phase centre variation as a function of the nadir angle is not absorbed by the estimates of any of the parameters. The phase centre variation is within approximately 20 mm. One value is estimated for each of the Block II/IIA and Block IIR satellite types. Individual estimates for the different satellites of a specific type show remarkable similarities regarding the nadir dependency.

The status of the analyses is that approximately 3214 daily SLR arcs (with Lageos I & II data from 1 Jan 1993 to 31 Dec 2001) have been processed where 744 arcs are combinations with VLBI and approximately 200 arcs are combinations with VLBI, GPS and SLR. Typically, 60 GPS stations are included in each arc. These 3214 arcs have been combined into a global solution using the CSRIFS program. A program called CSRIFS-IERS reads the output of CSRIFS and estimates a time dependent transformation from the internal terrestrial and celestial reference frames to an ITRF (presently ITRF2000) and an IERS Celestial reference frame (presently ICRF-95.ext). Since the estimated Earth orientation parameters in principle are 100 % consistent with the internal reference frames the time dependent transformation parameters can be applied to transform the EOP estimates to IERS for comparison with the IERS EOP products. A possible inconsistency between the IERS reference frames and the IERS EOP estimates should in principle be detectable. The CSRIFS-IERS automatically generates SINEX files for the terrestrial and celestial reference frames and the EOPs. These files can be directly submitted to the IERS product centres.

During the last year the following improvements have taken place in the GEOSAT software:

- The DE405 planetary ephemerides have been implemented.
- The planets Mercury, Mars, Uranus, Neptune and Pluto have been included.
- The IERS-2000 VLBI observation model has been implemented.
- The Mendes et al. SLR refraction model has been implemented.
- The following GPS satellites have been down-weighted: PRN 2, 15, 17, 21, and 23.
- A constant GPS satellite phase centre offset (z-coordinate) for each of the Block II/IIA and Block IIR satellite types has been estimated.

- Nadir-dependent GPS satellite phase centre variations for each of the satellite types have been estimated.

All improvements listed above have been applied in the analysis of the 3214 arcs.

The results from a corresponding analysis, excluding the GPS data, have been submitted to the ITRS Centre, the Rapid Service/Prediction Centre and the Earth Orientation Centre of the IERS.

References

Andersen, P. H. High-precision station positioning and satellite orbit determination. Ph.D. Thesis, NDRE/publication-95/01094. FFI/E, Box 25, N-2007, Kjeller, Norway.

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