Halfdan Pascal Kierulf et al.: VLBI Analysis with the Multi-technique Software GEOSAT, IVS 2010 General Meeting Proceedings, p.207–211
http://ivscc.gsfc.nasa.gov/publications/gm2010/kierulf.pdf

VLBI Analysis with the Multi-technique Software GEOSAT

Halfdan Pascal Kierulf [1], *Per-Helge Andersen* [2], *Sarah Boeckmann* [3], *Oddgeir Kristiansen* [4]

[1] *Norwegian Mapping Authority (NMA) and the University of Oslo (UiO)*
[2] *Forsvarets forskningsinstitutt (FFI) and the University of Oslo*
[3] *Institut für Geodäsie und Geoinformation (IGG-Bonn)*
[4] *Norwegian Mapping Authority*

Contact author: Halfdan Pascal Kierulf, e-mail: `halfdan.kierulf@statkart.no`

Abstract

GEOSAT is a multi-technique geodetic analysis software developed at Forsvarets Forsknings Institutt (Norwegian defense research establishment). The Norwegian Mapping Authority has now installed the software and has, together with Forsvarets Forsknings Institutt, adapted the software to deliver datum-free normal equation systems in SINEX format. The goal is to be accepted as an IVS Associate Analysis Center and to provide contributions to the IVS EOP combination on a routine basis. GEOSAT is based on an upper diagonal factorized Kalman filter which allows estimation of time variable parameters like the troposphere and clocks as stochastic parameters. The tropospheric delays in various directions are mapped to tropospheric zenith delay using ray-tracing. Meteorological data from ECMWF with a resolution of six hours is used to perform the ray-tracing which depends both on elevation and azimuth. Other models are following the IERS and IVS conventions. The Norwegian Mapping Authority has submitted test SINEX files produced with GEOSAT to IVS. The results have been compared with the existing IVS combined products. In this paper the outcome of these comparisons is presented.

1. Introduction

The production of Earth Orientation Parameters (EOPs) for the geodetic community is one of the main products of the IVS. Results from different IVS Analysis Centers (ACs) are combined, and the final IVS combined results are provided. However, the number of different analysis software packages is limited (see [3]), and the combined solution is dominated by the Calc/Solve [7] software. Contributions to the combination from additional independent software packages are strongly desired by the IVS to exclude the probability of deficits in any of the software packages. GEOSAT is a software developed at Forsvarets Forsknings Institutt (FFI). The Norwegian Mapping Authority (NMA) will produce EOP series with GEOSAT in the form of datum-free normal equation systems in SINEX format and thereby contribute to the IVS combination.

To produce VLBI solutions for IVS is the first part of a larger strategic plan from NMA. The next step is to include other geometric geodetic techniques (GNSS and SLR) in a common solution, where the different techniques are combined at the observation level. The long term goal of this large effort is to also include data from the gravity satellites GRACE and GOCE and from satellite altimetry.

In this paper the software will be shortly described (Section 2), and some preliminary results of the comparison with the solutions from other IVS ACs and the IVS combined product will be given (Section 3).

2. The GEOSAT Software

During the last 27 years, FFI has developed a software package called GEOSAT for the combined analysis of VLBI, GNSS (GPS, Galileo, GLONASS), SLR, and other types of satellite tracking data (e.g., DORIS, PRARE, altimetry, gravity, radar, direction, Deep Space Network). The observations are combined at the observation level with a consistent model and consistent analysis strategies. With this procedure, the time-evolution of the common multi-technique parameters (for example EOP, geocenter, troposphere, or clock parameters) is treated consistently across the techniques.

In the combined analysis with GEOSAT 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 Filter (SRIF) array 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 a stochastic parameter between the arcs. The estimation of multi-day stochastic parameters is possible and extensively used in the analyses.

A major software component of GEOSAT is a 3D raytracing through the atmosphere. A complete 3D atmospheric model provided daily by ECMWF is input to the software. Based on the available tracking data for that specific date, a set of tables for each active station is automatically generated with information about the time delay in the different elevation and azimuth directions. Also statistical information concerning the variability of relevant parameters is extracted from the ECMWF data. This information is used in the estimation filter as time-dependent parameter constraints. No mapping functions are used when numerical weather model data is available.

The latest electronically updated IERS Conventions have been fully implemented including the new EOP parameterization. Except for the treatment of the troposphere, the analysis strategy follows the recommendation from the IVS Analysis Coordinator. The atmospheric loading is modeled using time series from `http://gemini.gsfc.nasa.gov/aplo` ([6]). The a-posteriori RMS of fit for a VLBI session is typically 15–30 ps. The session-wise VLBI solutions for the IVS are based on NGS cards. Clocks and troposphere zenith wet delay are solved as stochastic parameters, while station positions and EOP are solved as constant parameters. From the session SRIF matrix, the necessary information is extracted, and the unconstrained normal equation is produced.

3. Results

The daily datum-free normal equation systems from GEOSAT are combined and compared with solutions from the other ACs, following the procedure explained in [3]. The overall impression of the results is that they are consistent with the results from the other ACs, except for some systematic differences. In this section we will look at some of the parameters and discuss these differences.

In Figure 1 coordinate time series for Ny-Ålesund are displayed for two different solutions: NMA using the software GEOSAT and Goddard Space Flight Center (GSFC) using the software CALC/SOLVE. The horizontal rate estimates are similar, but the noise level is larger in the NMA solution. The secular uplift is larger in the GSFC solution. However, the non-linear uplift pattern as reported in [4, 5] is seen in both solutions. In Figure 2, the residual time series for all IVS ACs are plotted for Ny-Ålesund (left) and Wettzell (right). We find a consistent pattern between all the

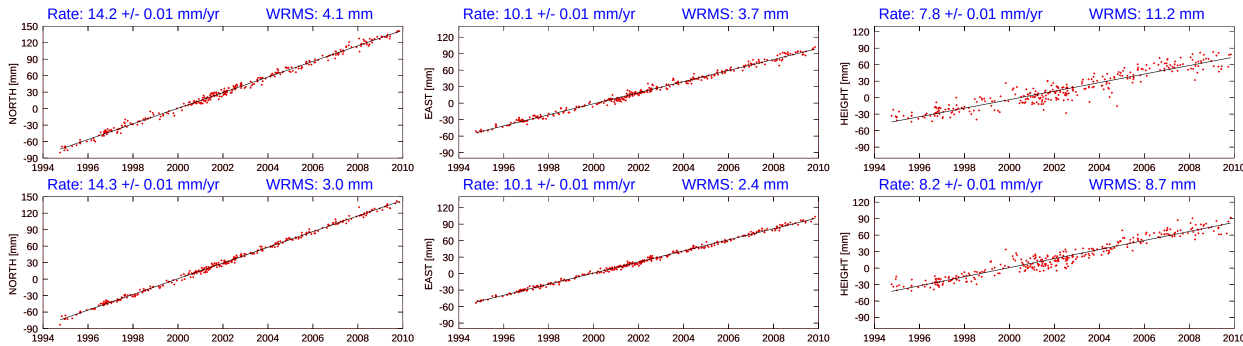

Figure 1. Time series of Ny-Ålesund from NMA (GEOSAT) (upper) GSFC (CALC/SOLVE) (lower).

solutions, but with some systematical differences. For instance, the east and height components for Wettzell are slightly biased both for the NMA and IAA (QUASAR) solutions compared with the other ACs. Similar biases are also found for some other stations.

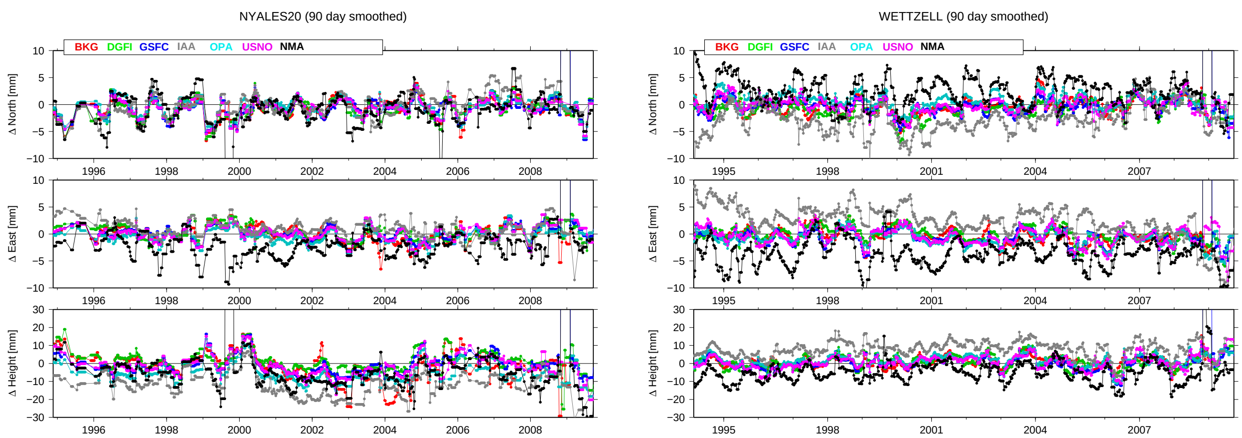

Figure 2. BKG, DGFI, GSFC, IAA, OPA, USNO, and NMA residual time series for Ny-Ålesund (left) and Wettzell (right). Individual time series can be distinguished by color in the electronic version.

The nutation parameters dX and dY of the celestial intermediate pole for all ACs are plotted in Figure 3. We find an annual signal both in the dX and dY components. The signal is similar to what we find in the IAA solution. Some minor errors that can explain the signal were found in the GEOSAT software. They are now fixed, and we expect to see an improvement in the next comparison.

The EOP for all ACs are plotted in Figure 4. The values are relative to the IVS combined solution (left) and the IGS combined solution (right). The *X-pole* and *Y-pole* components have similar variations as the other ACs compared to IVS combined. When we compare with the IGS solution, the noise level seems larger. Also the number of outliers is larger. The polar-motion rate (Figure 5) fit very well to the combined solutions and especially to the IGS combined solution. GEOSAT uses midnight as the reference epoch for the EOPs while the other ACs use mid-session. The NMA solutions are therefore extrapolated to mid-session while the rates are constant for the complete days. This may explain why the NMA solution fit the combined polar-motion rates very

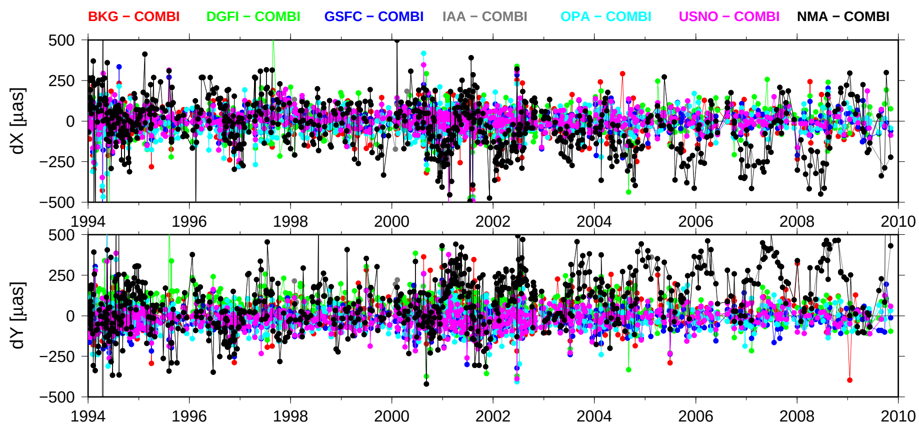

Figure 3. BKG, DGFI, GSFC, IAA, OPA, USNO, and NMA time series of nutation parameters in dX and dY vs. IVS-combined.

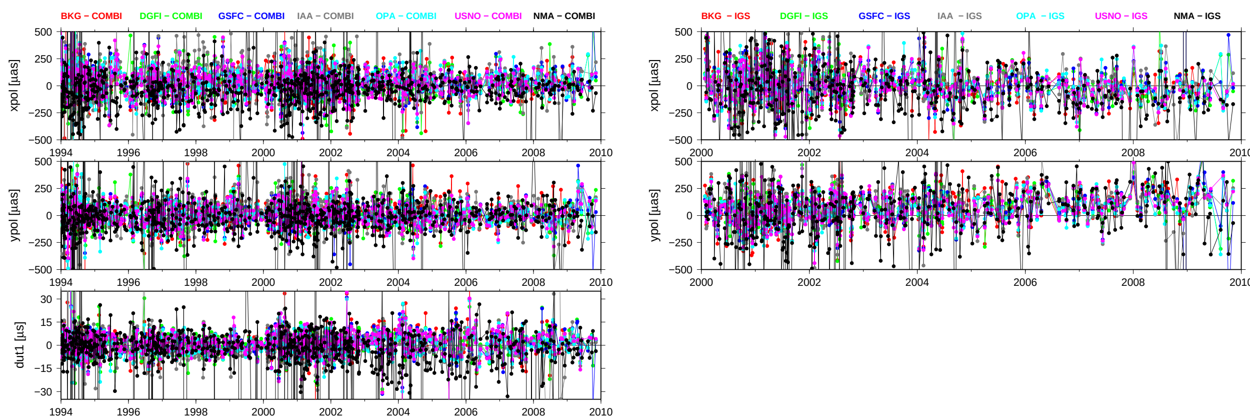

Figure 4. BKG, DGFI, GSFC, IAA, OPA, USNO, and NMA time series of polar motion vs. IVS combined (left) and vs. IGS combined (right).

well, while the fit to the polar-motion parameters seems worse.

For *UT1* we see several outliers and after around 2003 a number of sessions seem to have an offset. The *LOD* seems to be a bit noisier than at the other ACs.

As seen above the results for some of the parameters with GEOSAT seem to be somewhat more noisy than the results from the other ACs in the combination. This issue has lately been studied in more detail and has resulted in a strategy that gives more stable normal equations.

4. Conclusions

The overall agreement between the NMA-GEOSAT solution and the solutions from the other ACs is satisfactory for this first comparison. However, some discrepancies have been found. This reveals some issues that have to be investigated further. As soon as the causes for the discrepancies are understood and taken into acount, NMA will start to deliver VLBI solutions to IVS regularly.

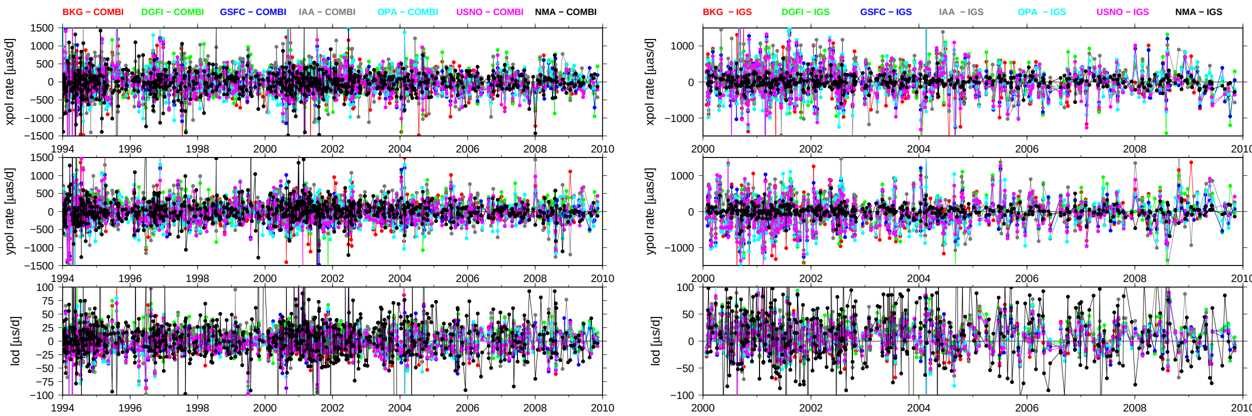

Figure 5. BKG, DGFI, GSFC, IAA, OPA, USNO, and NMA time series of polar motion rate vs. IVS combined (left) and vs. IGS combined (right).

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