NMA Analysis Center – Progress Report

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Abstract The Norwegian Mapping Authority is currently developing **Where**, a new software for geodetic analysis. The software will be used to analyze VLBI sessions and contribute to the rapid and other operational products of the International VLBI Service for Geodesy and Astrometry (IVS). All the components needed for the analysis of an individual VLBI session are finished in **Where** and the software is in its final testing phase. Together with the IVS Combination Center, the quality of the processed solutions are being evaluated and improved as problems are detected. The goal is to have a fully working version of the VLBI part of the software before the end of 2018.

Keywords VLBI, Where, software, analysis

1 Introduction

The Norwegian Mapping Authority (NMA) has been an Associate Analysis Center of the IVS [1, 9] since 2010. The original plan was to use the GEOSAT software [4] and become an operational Analysis Center, which regularly processes R1 and R4 sessions. As previously reported in the IVS 2015+2016 Biennial Report [5], the GEOSAT software was abandoned and a new software is under development. The new software is called **Where** [6]. The NMA plans to use this software to submit timely analyses to the IVS Combination Center (CCIVS).

Norwegian Mapping Authority

2 Motivation

The NMA has operated the VLBI station in Ny-Ålesund since the beginning of the 1990s with the first observations in 1994. The site is currently being upgraded with two new VLBI stations and an SLR station is planned to be added to the site by 2022. Several GNSS stations and a DORIS beacon already exist in Ny-Ålesund.

Ny-Ålesund is situated at 78.55°N, 11.56°E on the west coast of Spitsbergen, the largest island in the Svalbard archipelago. Ny-Ålesund is not open to the general public and professionals working there are limited to fixed term contracts. This naturally causes a high turnover and finding qualified personnel for a small field of science, such as VLBI and SLR, is a continuous challenge. Having qualified personnel in permanent positions at the head office is therefore essential. Creating, maintaining, and using an analysis software provides valuable compentence and insights into the field of VLBI for the group at the head office. Additionally, by becoming an Analysis Center, the NMA can finally analyze the data collected at Ny-Ålesund and provide direct feedback to the station on its performance.

3 Software

Figure 1 shows the architecture and basic pipeline for the analysis of a typical geodetic VLBI session. In 2017 the theoretical VLBI delay model of the **Where** software was confirmed to be comparable with other software packages [6]. This was done by utilizing the

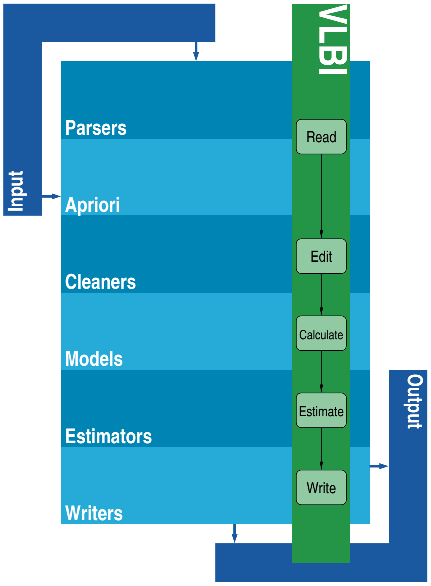

Fig. 1 **Where** architecture: The pipeline for the analysis of VLBI sessions.

data and analysis from the VLBI Analysis Software Comparison Campaign 2015 [7].

Where uses a Kalman filter with a Modified Bryson-Frazier smoother [2, 3] for estimation. Clocks and troposphere are modeled as continuous piecewise linear parameters. By default, the clocks and the wet troposphere are estimated with one linear segment per hour, while the horizontal gradients use one linear segment per six hours. Normal equations as requested by the IVS are created following the method of [8].

The **Where** software is available under an open source MIT license at `https://kartverket.github.io/where`.

4 Verification and Validation

Lately, a lot of effort has been put into analyzing sessions from 1994 to 2016 to identify clock breaks and other issues with the data. Furthermore, the estimator and writer components have been completed and a lot of testing has been done. Several solutions were submitted to the CCIVS for evaluation. Based on feedback from the CCIVS, several issues with the software were resolved. Table 1 summarizes the submitted solutions and their issues.

In March 2018 the first test solution was submitted to the CCIVS. It consisted of one year of sessions (2016) and contained estimates for Earth Orientation Parameters (EOP) and station coordinates. Briefly after, a solution with 23 years of processed sessions (1994–2016) was also submitted. The second solution also contained estimates for radio source coordinates. These solutions were processed by the same setup and version of the software.

However, there were some problems with the submitted solutions. First of all, the radio source names were wrong for those sources that are listed in the observation file with a different name than the official IERS name. This problem was resolved, but not yet verified by the CCIVS.

Secondly—and more worrisome—the estimates appeared to be extremely close to the a priori values. The first (and second) solution also contained large offsets in estimated station coordinates for some stations and the computed weight factor for the solution in the combination was too low.

The main problem was that when the Kalman filter iterated and removed outliers it did not estimate the parameters from scratch, but rather estimated a correction to the previous estimate. It was this correction to the previous estimate that was wrongly used to generate the normal equations.

The implementation of the creation of the normal equations also contained some minor bugs. All these mistakes were corrected in a new version of the software. A third solution with station coordinates and EOPs using sessions from 2013 to 2016 was then submitted at the end of May.

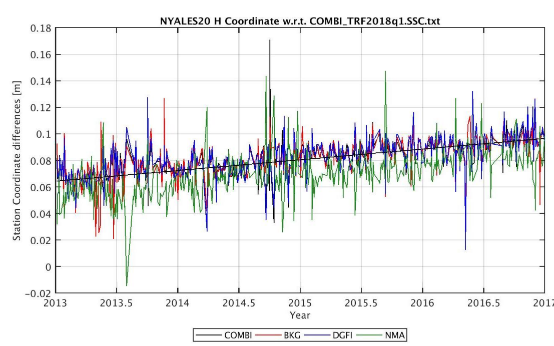

Fig. 2 Differences between the height component of NYALES20 and a reference frame solution from the third solution. Provided by Sabine Bachmann, BKG.

Table 1 Solutions submitted to the CCIVS for testing. The first column indicates the solution number and the second column shows which sessions were analyzed. All 24-hour sessions for a given year were submitted. The third column shows which parameters were included in the submitted normal equations. The fourth and fifth column describes the problems with the solutions and how these were improved in later solutions.

No.	Data	Parameters	Problems/Comments	Difference w.r.t. to previous solution
1	2016	Station coordinates EOP	Estimates too close to a priori Low weight factor in the combination	Initial solution
2	1994–2016	Station coordinates Source coordinates EOP	Same as above Problems with source names	Software unchanged
3	2013–2016	Station coordinates EOP	Wrong sign on estimates Worse weight factor in combination Offsets and high variability in EOP	Fixed bug that caused too small estimates
4	2002–2016	Station coordinates EOP	Variations in LOD Otherwise OK	Fixed bug with estimate sign Updated EOP C04 file Increased a priori standard deviations for EOP
5	2002–2016	Station coordinates Source coordinates EOP	Not analyzed yet	Fixed bug with LOD sign Corrected source names

The magnitude of the estimates now seemed to be reasonable and the estimates were no longer too optimistic. But they were still slightly different from the other Analysis Centers and the combined solution. They appeared to have the opposite sign. This can, for instance, be seen pretty clearly in the height component at Ny-Ålesund in Figure 2.

In addition, the offsets observed in the previous solutions and the weight factor became worse instead of better. This behavior is also consistent with the sign error. The problem was traced back to the residual vector that turned out to have the wrong sign.

There were also some problems with the EOPs. There was an offset in UT1–UTC and a large variability in the estimates for most of the parameters compared to the other Analysis Centers.

The sign error was corrected and an updated version of the a priori EOP 14 C04 file was downloaded, which had not been updated locally since September 2017. Since then, IERS has made several changes and fixed problems with this time series[1]. The latest change was in April 2018. Especially, the UT1–UTC time series had large differences. The standard deviations for the EOP used in the a priori covariance matrix in the Kalman filter were also increased, as some values were artificially low. The final values used are summarized in Table 2.

[1] http://hpiers.obspm.fr/iers/eop/eopc04/updateC04.txt

Table 2 Default a priori covariance matrix used in **Where**. The matrix is a diagonal matrix with σ^2 on the diagonal.

Parameter	σ
Constant parameters	
Station coordinates	1 m
UT1–UTC	10 ms
LOD	10 ms
Polar motion	100 mas
Polar motion rate	100 mas/d
Precession/Nutation	100 mas
Radio source coordinates	2.5×10^{-7} rad
Piecewise Linear Parameters (offset and rate)	
Clock	1 m and 1 m/h
Wet troposphere	1 m and 1 m/h
Horizontal gradients	1 m and 1 m/h

A fourth solution was submitted with processed sessions from 2002–2016 at the end of June. This time the results were more promising. The station coodinates and EOP estimates seemed to be comparable with other Analysis Centers. For instance, Figure 3 shows the height component at NYALES20, which clearly improved compared to Figure 2. Figure 4 shows the difference between the estimated UT1–UTC and the combined solution. Figure 5 shows the same but for LOD. The high variations in LOD are still a problem, but UT1–UTC and the other EOPs (not shown here) agree well with those from other Analysis Centers.

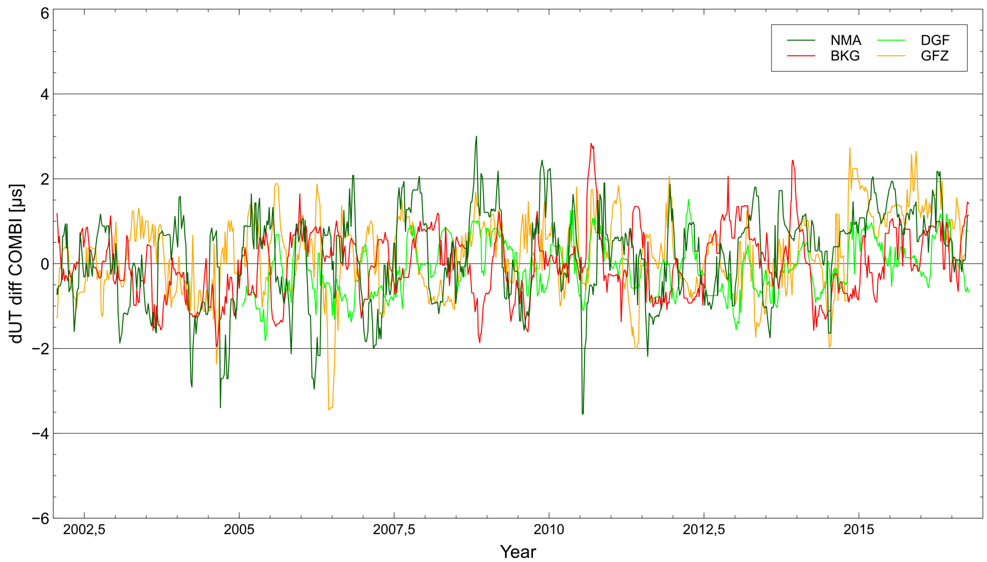

Fig. 4 Differences between UT1–UTC and the combined solution for different Analysis Centers from the fourth solution. Provided by Sabine Bachmann, BKG.

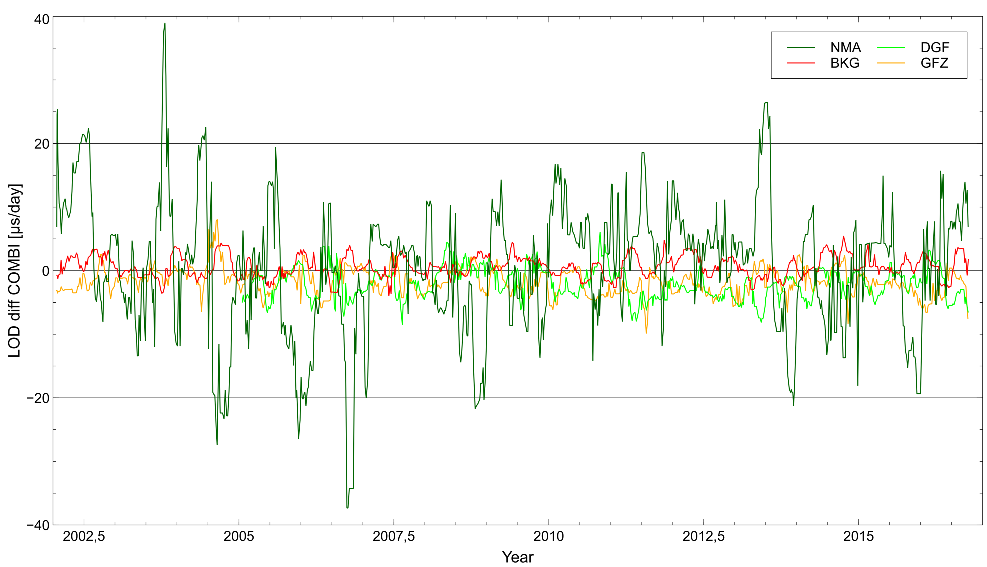

Fig. 5 Differences between LOD and the combined solution for different Analysis Centers from the fourth solution. Provided by Sabine Bachmann, BKG.

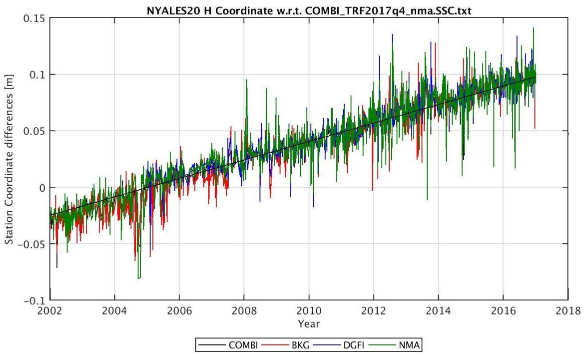

Fig. 3 Differences between the height component of NYALES20 and a reference frame solution from the fourth solution. Provided by Sabine Bachmann, BKG.

A sign error in the partial derivatives of the LOD parameter was discovered and the sesssions from 2002 to 2016 were processed again. This fifth and currently final solution was submitted in August, but has not yet been analyzed by the CCIVS. The LOD bugfix is expected to improve the LOD estimates, but it is still undecided how to compute a good a priori value for LOD, so a bit more work might be needed. In addition, this solution reintroduced radio source coordinates, but with correct source names. Feedback on the fifth solution is anticipated soon.

5 Future Work

The immediate plan is to continue to submit analyzed sessions to the CCIVS to improve the quality of the solution. When the estimates of station coordinates and the EOP seem reasonable, the source coordinates will be added again. Also, with the disappearance of the NGS card file format, the vgosDb file format parser needs to be tested more extensively and improved.

When the quality is approved, the next step is to start analyzing regularly the R1 and R4 sessions and to establish good routines for upholding the timeliness requirement. The plan is to start regular analysis by the end of 2018. This step will involve a different set of challenges such as automation of the analysis and having qualified personnel available during vacations.

In addition, outliers should be studied more closely. Some sessions do not have enough usable observations to estimate the full set of parameters. These sessions require special handling, which complicates the road to automating (as much as possible) the analysis.

Finally, models need to be updated as new conventions and analysis strategies are being implemented in preparation for the next international terrestrial reference frame solution projected for 2020.

Acknowledgements

Thanks to Sabine Bachmann (BKG) at the IVS Combination Center for analyzing our solutions and providing great feedback and insights.

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