Norwegian Mapping Authority Analysis Center 2017–2018 Report

Ann-Silje Kirkvik

Abstract During 2017 and 2018, the Norwegian Mapping Authority has continued the development of the analysis software **Where** that was started in 2015. The goal is to be able to use this software to analyze VLBI data and contribute to operational IVS products. Extensive testing of the software has been performed by analyzing over 20 years of 24-hour sessions and submitting the solution to the IVS Combination Center for comparison with other analysis centers. After seven submissions with intermediate corrections of detected problems, **Where** finally produced results that were comparable to other analysis centers and were ready to be included in the IVS combination. Once the quality of the results were verified, the next step was to start regular operational submissions to test timeliness and operational robustness. This activity is anticipated to continue throughout 2019.

1 General Information

The Norwegian Mapping Authority (NMA) has been an Associate Analysis Center within the IVS since 2010. The analysis center is operated by the Geodetic Institute at NMA with main offices in Hønefoss, Norway. NMA is a governmental agency with approximately 800 employees, and the IVS activities at NMA are completely funded by the Norwegian government.

NMA is using the analysis software **Where**, which is developed at NMA. The goal is to be able to use this software to analyze VLBI data and contribute to operational IVS products. **Where** is freely available as open source at GitHub[1]. Currently, the released version of **Where** can process individual VLBI sessions. **Where** relies on vgosDB version 4 as input, and, for the moment, it only supports the legacy S/X observations.

Development is underway to support SLR and various applications of GNSS data. In addition, a lot of the functionality in **Where** has been separated into a library called **Midgard**, which is also available on GitHub under the same license[2].

2 Staff

The Geodetic Institute at NMA has approximately 50 employees. Some of the responsibilities include maintaining the national reference frame, geoid, and height system. The Geodetic Institute also provides a network-RTK positioning service and operates the VLBI station in Ny-Ålesund.

The **Where** development team has lost a few members due to changes in priorities and resignations, but it has also gained some resources. The current staff is summarized in Table 1.

3 Current Status and Activities

NMA has been working on the development of **Where** since August 2015. In spring 2017, the software demonstrated the ability to calculate theoretical delays

Norwegian Mapping Authority (NMA)

NMA Analysis Center

IVS 2017+2018 Biennial Report

[1] https://kartverket.github.io/where

[2] https://kartverket.github.io/midgard

Table 1 **Where** developers and users at NMA.

Name	Tasks
Laila Løvhøiden	System owner
Michael Dähnn	GNSS developer
Mohammed Ouassou	GNSS developer
Ingrid Fausk	SLR developer
Ann-Silje Kirkvik	VLBI developer
Åsmund Skjæveland	VLBI analyst

comparable to other software packages [2]. This was done by comparing results from **Where** with results obtained in the VLBI Analysis Software Comparison Campaign 2015 [4].

By the beginning of 2018, all the building blocks needed to do a complete analysis of a VLBI session were completed, but a lot of testing and validation remained [3].

At the 10th IVS General Meeting in Longyearbyen **Where** was released as an open source software [1]. At the time there were still some problems to solve before the results obtained with **Where** were reliable, but the General Meeting seemed like a suitable arena for making the announcement. The choice of releasing **Where** as open source was twofold. For one, it would enable greater transparency about how results obtained with **Where** actually are produced. Additionally, it opens up the possibility for others outside NMA to contribute to the software.

After the General Meeting, the testing and improvement of **Where** continued. After submitting a total of six solutions to the IVS Combination Center (CCIVS), **Where** finally produced results that were ready to be included in the combination. The sixth solution contained all 24-hour sessions from the beginning of 2002 to the end of 2017.

However, the abrupt hardware failure of some critical components in the IVS production chain forced the transition from NGS file format to the vgosDB format for the VLBI observables. All submitted solutions up to this point were based on the NGS file format. Therefore, to test the vgosDB format a seventh solution was analyzed and submitted to the CCIVS. The seventh solution contained all 24-hour sessions from the beginning of 1994 to the end of 2018.

With the exception of some differences in the quality code flag for some observations for some older sessions, the vgosDB data seemed to produce the same results as the NGS files. There were also some larger differences compared to the combined solution in the parameter estimates for the older data (1994–2002) that was only included in the latest solution (Figure 1). This should be investigated further. One possibility is that the same parameterization was used for the whole dataset regardless of session geometry and might have an effect on the results before and after R1s and R4s were introduced in 2002.

However, for newer sessions **Where** v0.16.2 and higher seems to produce results that can be included in the IVS combination. The statistics of the Earth Orientation Parameters (EOP) for the seventh solution are summarized in Table 2, and Figure 1 shows the value of UT1–UTC compared to the combination for the same solution.

In relation to the new antennas being built in Ny-Ålesund [5], NMA and IGN (Spain) have a "Memorandum of Understanding" where IGN develops the broadband receivers for the new antennas and NMA provides the analysis software **Where** and some training to IGN. In November 2018, four people from IGN visited NMA in Oslo, and a VLBI analysis workshop with **Where** was held for five days (Figure 2). IGN also plans to use **Where** to become an analysis center.

4 Future Plans

With the promising results from the testing period, NMA is now ready to try to contribute to the operational analyses. The submission of regular timely analyses of R1 and R4 sessions will start at the beginning of 2019. NMA also plans to contribute to the next realization of the international terrestrial reference frame (ITRF2020).

The development of **Where** will also continue. Some possible extensions are to support analysis of VGOS data, support vgosDB version 1, provide better support for analysis of Intensive sessions, support estimation of global solutions across multiple sessions, support different estimators, or to look into further automation of the analysis. It is still not decided which of these tasks should be prioritized.

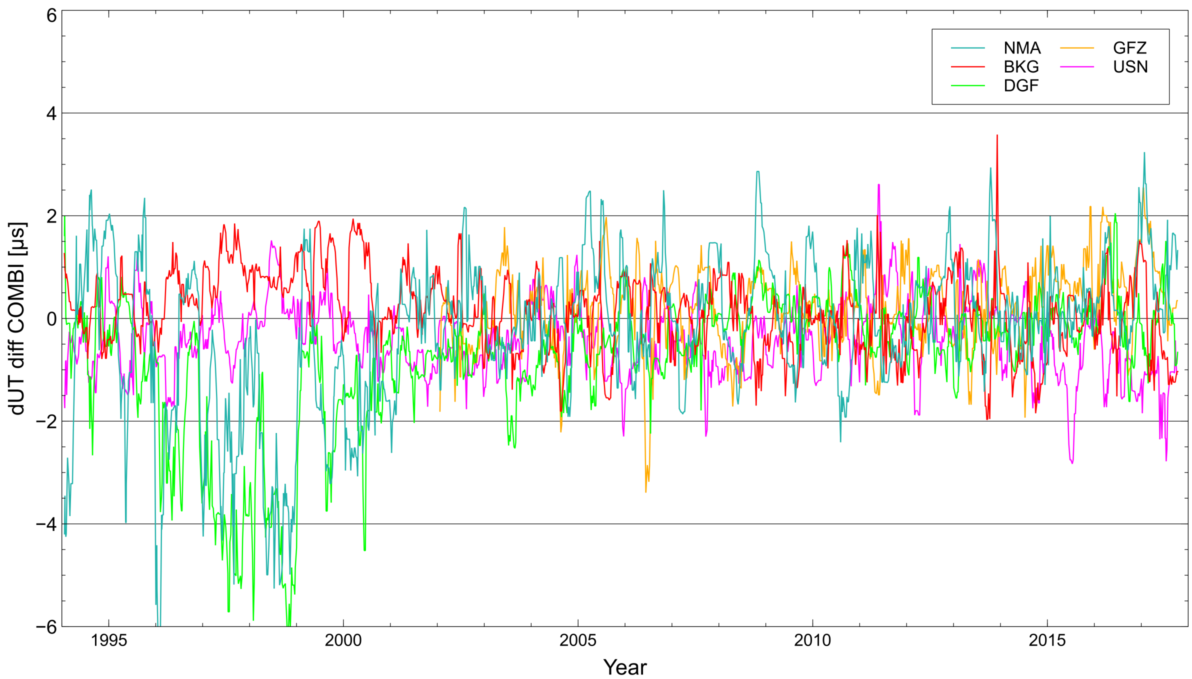

Fig. 1 Difference between UT1–UTC and the combined solution for different analysis centers from the seventh solution. Provided by Sabine Bachmann, BKG.

Fig. 2 Workshop with IGN (Spain) at NMA offices in Oslo in November 2018. From the left: Ann-Silje Kirkvik, Susana Garcia Espada, Yaiza Gómez Espada, Victor Puente, and Esther Azcue. Photo: Geir Arne Hjelle.

Table 2 Statistics for a combined solution of the EOP parameters: Polar motion (x_p, y_p), Polar motion rate $(\dot{x}_p, \dot{y}_p)$, UT1–UTC, Length of Day (LOD), and Celestial Pole Offset (dX, dY). Provided by Sabine Bachmann, BKG.

AC	WRMS	RMS	Offset	Offset σ	Rate	Rate σ	WRMS	RMS	Offset	Offset σ	Rate	Rate σ
	x_p $[\mu as]$						y_p $[\mu as]$					
COMBI	85.482	147.797	4.996	2.005	-3.899	0.257	84.872	137.949	17.215	1.904	0.624	0.253
BKG	104.468	167.126	12.367	2.247	-4.980	0.301	102.267	159.001	19.341	2.140	0.880	0.293
ASI	93.082	154.545	10.131	2.057	-4.881	0.270	90.687	141.814	23.470	1.888	1.091	0.256
DGFI	64.588	178.511	36.369	2.256	-5.143	0.305	57.148	141.185	0.466	1.977	-0.715	0.270
GFZ	100.864	171.606	8.712	2.367	-7.669	0.454	99.952	173.951	13.286	2.283	0.075	0.454
GSFC	89.657	144.076	14.993	2.029	-5.319	0.267	89.160	138.541	21.088	1.885	0.737	0.257
IAA	105.975	162.680	24.609	3.179	-4.749	0.403	105.060	150.436	21.690	2.772	3.429	0.358
NMA	112.984	234.652	21.267	2.385	-6.474	0.336	113.388	414.675	15.222	2.295	-0.391	0.337
OPA	90.188	150.517	11.564	1.997	-4.737	0.266	89.323	149.928	23.111	1.854	0.966	0.257
USNO	90.251	143.294	20.773	2.179	-4.920	0.286	91.614	140.434	27.073	2.076	0.995	0.280
VIE	213.394	247.003	25.398	6.620	-4.159	1.303	178.649	213.642	21.028	5.347	3.994	1.089
	$\dot{x}_p$ $[\mu as/d]$						$\dot{y}_p$ $[\mu as/d]$					
COMBI	264.471	469.659	-24.695	6.050	-0.919	0.788	247.053	450.571	-8.792	5.451	1.947	0.734
BKG	325.188	566.456	-39.181	7.290	1.910	0.961	310.450	537.123	-30.838	6.647	1.613	0.911
ASI	308.093	499.264	-32.979	6.590	1.587	0.877	288.749	460.081	-14.195	5.948	1.098	0.817
DGFI	183.665	533.381	-98.879	7.057	-4.252	0.951	194.537	542.673	-154.085	7.713	-16.915	1.045
GFZ	319.974	501.040	-20.847	7.511	2.294	1.465	316.942	647.830	-26.661	7.258	-1.871	1.461
GSFC	283.276	459.236	-48.099	6.182	2.489	0.828	274.679	425.088	-22.325	5.753	1.654	0.795
IAA	308.771	465.454	-73.600	8.691	3.182	1.095	315.316	435.988	-30.030	8.094	3.668	1.049
NMA	413.736	1688.182	-14.232	8.724	-1.461	1.219	389.543	1603.694	-52.370	7.899	5.033	1.147
OPA	303.316	549.385	-43.161	6.477	2.196	0.878	286.488	554.111	-20.991	5.887	0.762	0.827
USNO	283.643	458.030	-45.041	6.664	2.638	0.876	273.728	431.237	-20.899	6.169	1.777	0.835
VIE	522.554	764.064	18.635	15.751	-4.356	3.230	524.599	820.935	31.969	16.131	8.995	3.219
	UT1–UTC $[\mu s]$						LOD $[\mu s/d]$					
COMBI	9.159	11.505	-2.073	0.170	0.435	0.030	17.719	27.904	-2.200	0.370	0.410	0.055
BKG	9.455	11.856	-2.482	0.175	0.428	0.031	19.590	29.297	-0.925	0.393	0.139	0.059
ASI	9.301	11.513	-2.000	0.172	0.389	0.030	19.432	26.668	-0.322	0.375	0.159	0.058
DGFI	9.987	12.430	-2.980	0.186	0.545	0.034	8.860	30.054	0.016	0.426	1.534	0.058
GFZ	6.981	11.189	-0.691	0.185	0.155	0.039	19.103	36.399	-2.388	0.429	0.086	0.088
GSFC	9.118	11.127	-2.333	0.169	0.416	0.030	19.083	27.683	-0.686	0.373	0.204	0.059
IAA	10.231	10.965	-4.327	0.223	0.501	0.036	21.588	25.348	-1.667	0.512	0.082	0.072
NMA	10.367	14.944	-2.194	0.203	0.511	0.037	22.785	70.958	-4.430	0.450	0.379	0.072
OPA	9.199	12.245	-2.385	0.171	0.416	0.030	19.479	31.390	-0.518	0.378	0.210	0.059
USNO	8.937	10.735	-3.124	0.178	0.434	0.032	19.342	27.826	-0.244	0.410	0.164	0.063
VIE	15.821	16.683	-0.944	0.515	-0.003	0.101	56.137	63.877	-1.526	1.609	0.228	0.344
	dX $[\mu as]$						dY $[\mu as]$					
COMBI	45.741	70.212	-5.969	0.963	-2.202	0.128	40.390	80.073	1.771	0.862	1.777	0.114
BKG	67.782	94.817	-6.517	1.413	-2.870	0.191	61.826	100.966	0.188	1.308	2.666	0.175
ASI	53.265	75.964	-8.905	1.075	-1.367	0.145	49.918	88.444	2.044	1.017	1.650	0.137
DGFI	40.674	105.057	-19.264	1.418	-5.223	0.192	34.031	106.957	0.566	1.223	1.328	0.165
GFZ	78.905	110.921	-13.869	1.808	-4.343	0.360	73.225	122.437	10.874	1.686	4.505	0.335
GSFC	47.793	70.765	-16.549	0.981	-1.332	0.133	44.033	77.582	0.194	0.915	1.705	0.124
IAA	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
NMA	94.091	221.678	-17.820	1.863	-3.208	0.264	91.552	214.698	7.402	1.837	3.001	0.260
OPA	48.586	86.868	-8.856	0.979	-1.306	0.135	48.760	91.834	-0.009	0.994	1.539	0.136
USNO	52.302	68.892	18.141	1.157	-2.195	0.154	46.457	65.989	9.763	1.042	0.639	0.139
VIE	92.079	142.458	-13.915	2.796	-1.193	0.564	94.641	139.353	-3.818	2.890	2.115	0.582

Acknowledgements

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

References

1. Hjelle, G. A., et al., Making Where available to the community. In: Armstrong, K. L., Baver, K. D, Behrend, D. (eds.), *International VLBI Service for Geodesy and Astrometry 2018 General Meeting Proceedings*, NASA/CP-2019-219039, pp. 199–203, 2019.
2. Kirkvik, A.-S., et al., Where - a new software for geodetic analysis: In: Haas, R., Elgered, G. (eds.), *Proceedings of the 23rd European VLBI Group for Geodesy and Astrometry Working Meeting*, 2017.
3. Kirkvik, A.-S., et al., NMA Analysis Center – Progress Report. In: Armstrong, K. L., Baver, K. D., Behrend, D. (eds.), *International VLBI Service for Geodesy and Astrometry 2018 General Meeting Proceedings*, NASA/CP-2019-219039, pp. 237–241, 2019.
4. Klopotek, G., et al., Results from the VLBI analysis software comparison campaign 2015. In: Behrend, D., Baver, K. D., Armstrong, K. L. (eds.), *International VLBI Service for Geodesy and Astrometry 2016 General Meeting Proceedings*, NASA/CP-2016-219016, pp. 203–207, 2016.
5. Kupiszewski, P., Ny-Ålesund Geodetic Observatory. In: K. L. Armstrong, K. D. Baver, and D. Behrend (eds.) *International VLBI Service for Geodesy and Astrometry 2017+2018 Biennial Report*, this volume.