Geophysica (2019), 54(1), 19–25

Earth Orientation Parameters from the CONT17 Campaign

T. Nilsson[1], *K. Balidakis*[2], *R. Heinkelmann*[2] *and H. Schuh*[2]

[1]Lantmäteriet, Gävle, Sweden
[2]GFZ German Research Centre for Geosciences Potsdam, Germany

(Submitted: October 30, 2018; Accepted: March 28, 2019)

Abstract

In this work, we study the Earth Orientation Parameters (EOP) estimated from the continuous VLBI campaign CONT17. This campaign consisted of two station networks observing in parallel for 15 days, allowing for interesting comparison of the results. We find that the WRMS differences between the EOP estimated from the two networks are in the range 40–70 µas. Similar agreement is found with the polar motion estimated from GNSS. We also investigate the high frequency EOP variations and confirm earlier findings that the current IERS model for high frequency EOP variations needs to be updated.

Keywords: VLBI, Earth rotation, CONT17, Data analysis

1 Introduction

Normally, only two to four 24-hour VLBI (Very Long Baseline Interferometry) sessions are observed every week, and the participating stations change between the sessions. Occasionally, however, special efforts are made to have continuous VLBI observations over two weeks using a single station network; the so called CONT campaigns. The data from the CONT campaigns have been used for many different investigations, like studying the Earth Orientation Parameters (EOP) (e.g. *MacMillan*, 2017; *Karbon et al*., 2017) or the tropospheric parameters (e.g. *Teke et al*., 2013; Heinkelmann *et al*., 2016).

The most recent CONT campaign was the CONT17 campaign, which was observed from 28 November until 12 December, 2017 (*Behrend et al*., 2017). An interesting feature in this CONT campaign, compared to the previous ones, was that there were two station networks observing in parallel (see Fig. 1). The first network (hereinafter the IVS network) consisted of 14 globally distributed IVS (International VLBI Service for Geodesy and Astrometry) stations, while the other network (the VLBA network) contained nine stations from the Very Long Baseline Array (VLBA) in the USA augmented by four IVS stations to improve the global coverage. In addition, for five days of the campaign a third network was also observing, consisting of six new VGOS (VLBI Geodetic Observing System) antennas. The data from this third network are, however, not used in this work.

In this work we investigate the EOP estimated from the CONT17 campaign. We compare the results obtained from the two networks. We also compare with the estimates from GNSS (Global Navigation Satellite Systems) provided by IGS (International GNSS Service), and study potential improvements stemming from a combination of the two networks. Finally, we investigate the high frequency (sub-diurnal) variations in polar motion and universal time (UT1-UTC).

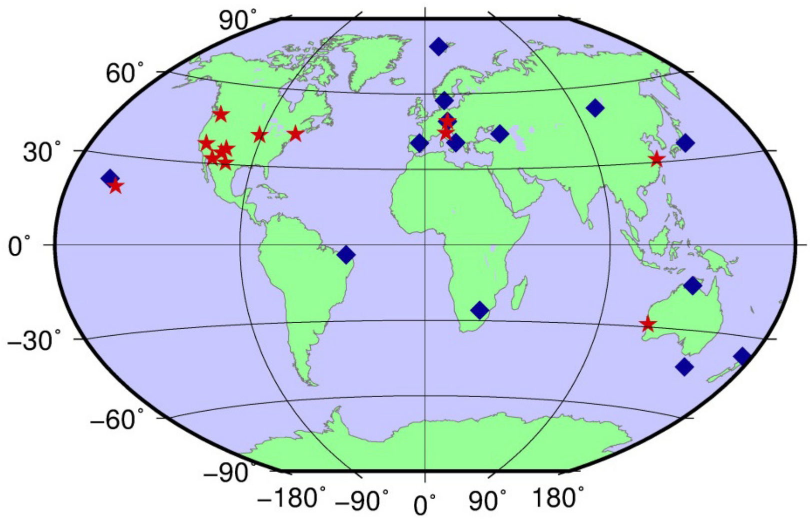

Fig. 1. The CONT17 networks. Blue diamonds and red stars denote the stations of IVS and VLBA networks, respectively

2 Data analysis

The CONT17 data were analyzed with the VieVS@GFZ software (*Nilsson et al.*, 2015). In a first step, the data from each of the 30 24-hour sessions (15 for each network) were analyzed individually. The a priori modeling basically followed the IERS (International Earth Rotation and Reference System Service) Conventions (*Petit and Luzum*, 2010), except that we also corrected for non-tidal geophysical loading due to the atmosphere, oceans, and hydrology[1]. We estimated station coordinates, radio source coordinates, EOP (polar motion, UT1-UTC, and celestial pole offsets), clock parameters, zenith tropospheric delays, and tropospheric gradients. After this first step, also a second analysis step was performed. In this step, all sessions from each network were combined in a global solution, estimating one set of station and radio source coordinates valid for the whole CONT17 campaign, as well as continuous EOP time series. Furthermore, we also calculated a global solution where the two networks were combined. For all cases we calculated two different solutions. In the first one, all EOP were estimated with daily resolution. In the second solution polar motion and UT1-UTC were estimated with hourly resolution and the celestial pole offsets were fixed to their a priori values from the USNO (U.S. Naval Observatory) final solution. This was done to avoid prob-

[1] https://isdc.gfz-potsdam.de/esmdata/loading/

lems related to the high correlation between polar motion and celestial pole offsets which exist when estimating these parameters with sub-daily temporal resolution.

3 Results

3.1 Earth Orientation Parameters, daily resolution

Figure 2 shows the WRMS (Weighted Root Mean Square) differences between the EOP estimated from the two networks, as well as the WRMS differences between the combined solution and the single-network solutions. We can see that the WRMS differences between EOP from the two networks are about 40–70 μas. When comparing with the combined solution, we find the best agreement with the IVS solution, where the WRMS differences are less than 20 μas for all EOP except UT1-UTC. This is because the IVS network has the highest impact on the EOP of the combined solution. The reason for this is that the IVS network has a better sensitivity to the EOP due to its better global distribution of the stations. In particular, the VLBA network has shorter baselines in the north-south direction (e.g., there is only one station in the southern hemisphere), what reduces the sensitivity in particular to polar motion. For UTl-UTC the impact of the VLBA network on the combined solution is higher because it contains several long east-west baselines, what is needed for a good sensitivity t o UTl-UTC.

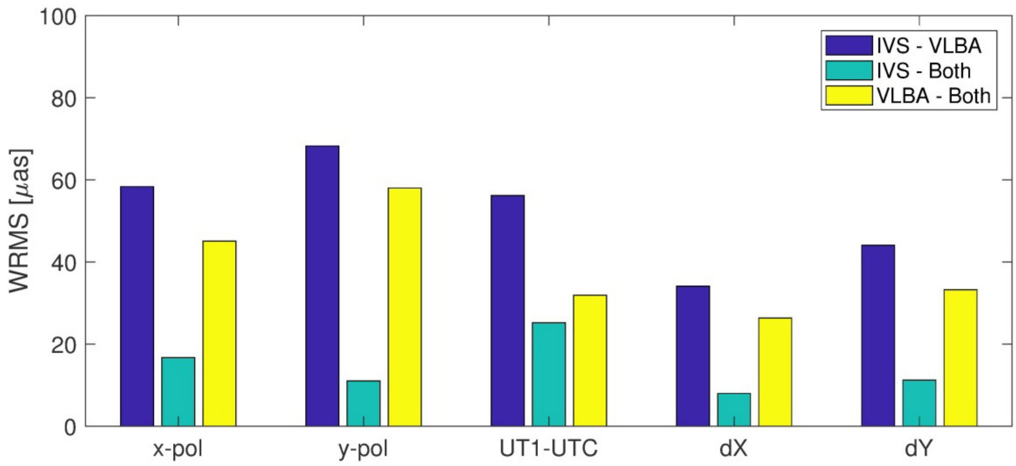

Fig. 2. WRMS differences between the EOP obtained from the two networks, as well as w.r.t the combined solution using both.

As an external reference, we also compared the estimated EOP to those obtained from GNSS (the IGS final solution). The WRMS differences w.r.t. the IGS solution can be seen in Fig. 3. Shown are all EOP which can be estimated by GNSS, i.e. polar motion, polar motion rate, and Length of Day (LOD). We can see that both networks as well as the combined solution agrees with IGS at approximately the same level for x-pole and its rate. However, for y-pole, and its rate, the agreement is better for the IVS network and the combined solution, compared to the VLBA network. This makes sense since a good sensitivity to y-pole requires baselines with a large extension in the y (or z) direction. Since most baselines in the VLBA network are in North America and thus have a short extension in the y direction, we can expect a smaller sensitivity to y-pole from this network. For LOD, however, the agreement between the VLBA network and IGS is better than between the IVS network and IGS. As discussed above, the VLBA network has some long baselines in east-west direction which provides a high sensitivity to UTl-UTC and LOD.

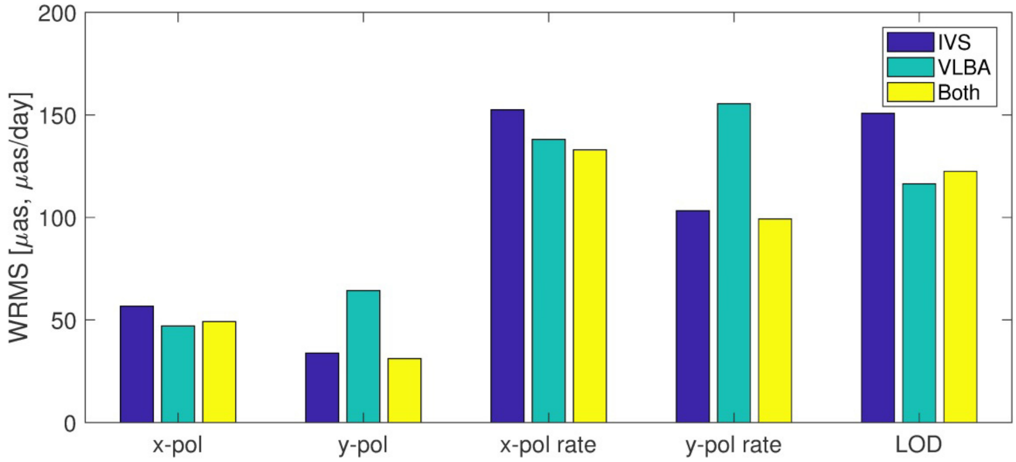

Fig. 3. WRMS differences between the EOP obtained from the two VLBI networks and the combined solution w.r.t the IGS final solution.

3.2 *Earth Orientation Parameters, hourly resolution*

To study the high frequency EOP variations, we estimated polar motion and UT1-UTC with hourly resolution. From the estimated time series we removed the values from the USNO final solution (daily resolution) to reduce the low-frequency variations, as well as the IERS model for high frequency (HF) EOP variations (*Petit and Luzum*, 2010). The IERS HF model describes the variations caused by ocean tides as well as libration. We then calculated the Fourier spectra for the remaining polar motion and UT1-UTC residuals. These spectra can be seen in Figs. 4–6.

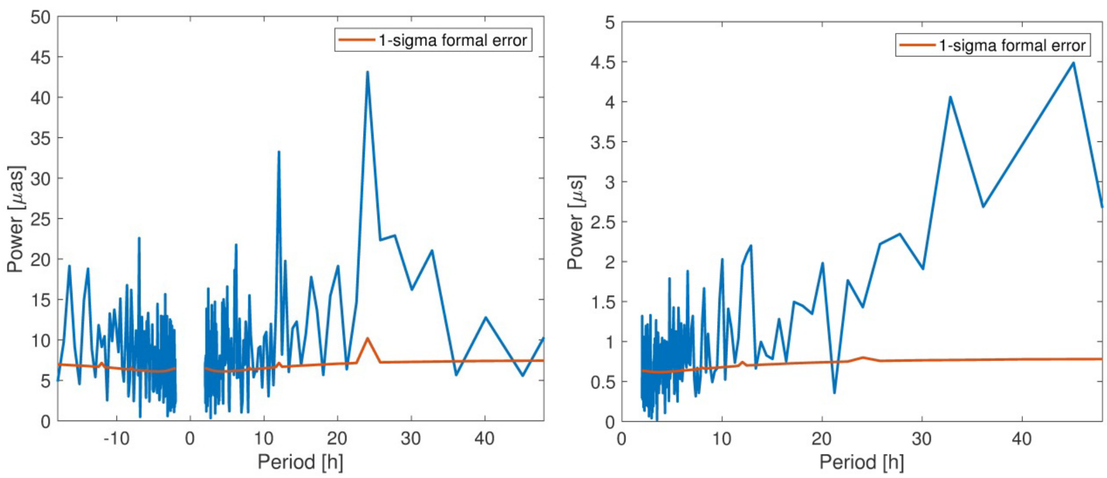

Fig. 4. Spectra of the high frequency residual polar motion ($p = x_p - i\,y_p$, left) and UT1-UTC (right) variations after removing the USNO final solution and the IERS high frequency model. Shown are the results from the IVS network.

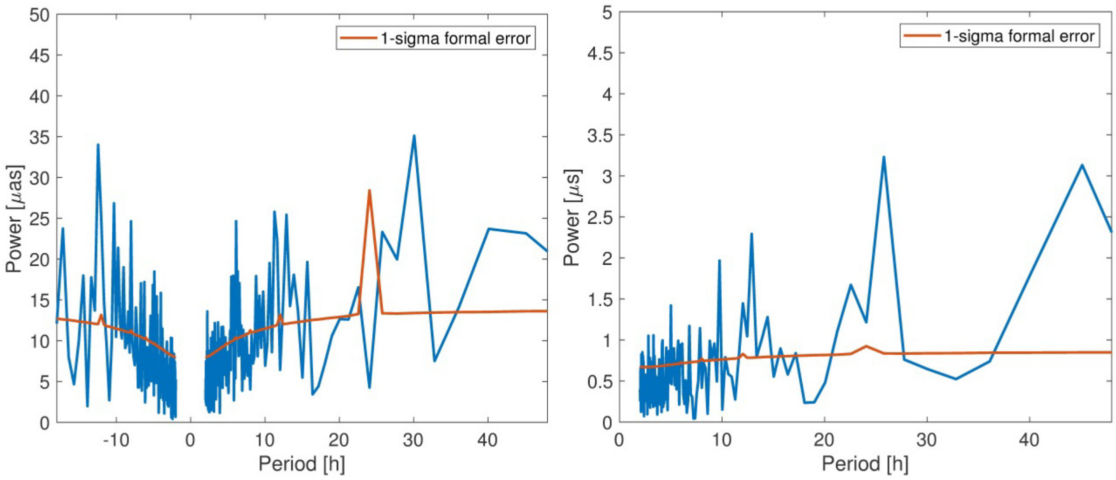

Fig. 5. Same as in Fig. 4, except shown are the results from the VLBA network.

Should the IERS HF model be error free and the EOP estimates from our VLBI analysis be systematic-error-free, we would expect to see no significant peak in the residual spectra. As seen in Figs. 4–6, this is not the case. There are peaks at tidal frequencies, such as 24 h and 12 h. Interesting is also a peak at about +6 h in the polar motion spectra, where such a strong variation (20–25 μas) is generally not expected and the IERS HF model does not contain any terms close to this period (it only contains periods close to 24 h and 12 h). The reason for the peaks at the tidal frequencies could be either systematic errors in the VLBI solutions, errors in the IERS HF model, or both. Since the spectra obtained from the IVS and VLBA networks are not in perfect agreement, e.g. there is a peak at -12 h for the VLBA network which is not present for the IVS network,

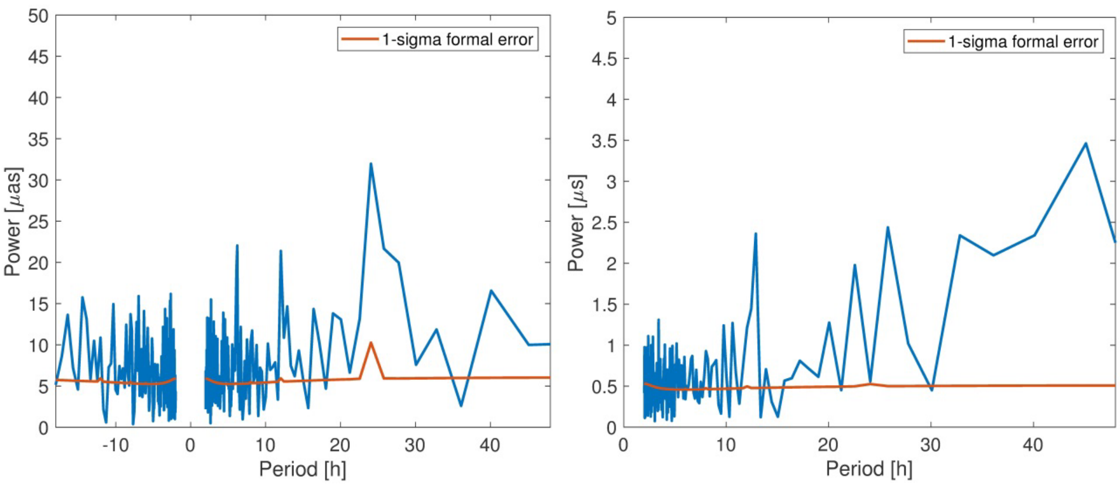

Fig. 6. Same as in Fig. 4, except shown are the results from the combined solution.

systematic errors in the VLBI solutions are probably present. This could for example be related to the observed radio sources. Since the same radio source tends to be scheduled to be observed by the same stations at about the same time every day, any errors related to a radio source could easily produce systematics with a period of about 1 day (or higher harmonics) (*Nilsson et al.*, 2012). An indication that this is an issue is the larger EOP formal errors for the +24 h period, which is likely due to high correlation between the EOP and the radio source position estimates. Furthermore, there might be station related errors with diurnal or sub-diurnal frequencies present. However, since some of the peaks show up in both networks (and also the combined solution), e.g. at +12 h and +24 h, it is also likely that the IERS HF model contains errors. This was also found in many other studies, e.g. *Artz et al*. (2012) and *Karbon et al*. (2017). There is an IERS working group currently making progess on updating the IERS HF EOP model.

4 Conclusions and future work

The fact that the CONT17 campaign used two independent networks allows for interesting comparisons. As we have seen, the two networks gave similar results. In general, the precision was slightly better for the IVS network, probably due to the better geometric distribution of the stations.

In the future we will continue the study of the CONT17 results. In particular, we will investigate the reasons for the different HF EOP variations obtained from the two networks. Furthermore, we will study other parameters, like the tropospheric delays. We will also include the data from the VGOS network in the analysis.

Acknowledgements

We are grateful to all parties that contributed to the success of the CONT17 campaign, in particular to the IVS Coordinating Center at NASA Goddard Space Flight Center (GSFC) for taking the bulk of the organizational load, to the GSFC VLBI group for preparing the legacy S/X observing schedules and MIT Haystack Observatory for the VGOS observing schedules, to the IVS observing stations at Badary and Zelenchukskaya (both Institute for Applied Astronomy, IAA, St. Petersburg, Russia), Fortaleza (Rádio Observatório Espacial do Nordeste, ROEN; Center of Radio Astronomy and Astrophysics, Engineering School, Mackenzie Presbyterian University, Sao Paulo and Brazilian Instituto Nacional de Pesquisas Espaciais, INPE, Brazil), GGAO (MIT Haystack Observatory and NASA GSFC, USA), Hartebeesthoek (Hartebeesthoek Radio Astron- omy Observatory, National Research Foundation, South Africa), the AuScope stations of Hobart, Katherine, and Yarragadee (Geoscience Australia, University of Tasmania), Ishioka (Geospatial Information Authority of Japan), Kashima (National Institute of Information and Communications Technology, Japan), Kokee Park (U.S. Naval Observatory and NASA GSFC, USA), Matera (Agencia Spatiale Italiana, Italy), Medicina (Istituto di Radioastronomia, Italy), Ny Ålesund (Kartverket, Norway), Onsala (Onsala Space Observatory, Chalmers University of Technology, Sweden), Seshan (Shanghai Astronomical Observatory, China), Warkworth (Auckland University of Technology, New Zealand), Westford (MIT Haystack Observatory), Wettzell (Bundesamt für Kartographie und Geodäsie and Technische Universität München, Germany), and Yebes (Instituto Geográfico Nacional, Spain) plus the Very Long Baseline Array (VLBA) stations of the Long Baseline Observatory (LBO) for carrying out the observations, to the staff at the MPIfR/BKG correlator center, the VLBA correlator at Socorro, and the MIT Haystack Observatory correlator for performing the correlations and the fringe fitting of the data, and to the IVS Data Centers at BKG (Leipzig, Germany), Observatoire de Paris (France), and NASA CDDIS (Greenbelt, MD, USA) for the central data holds. We are also grateful to the two reviewers for their comments.

References

T. Artz, L. Bernhard, A. Nothnagel, P. Steigenberger and S. Tesmer, 2012. Methodology for the combination of sub-daily Earth rotation from GPS and VLBI observations. *J. Geodesy*, **86**, 221–239. doi: 10.1007/s00190-011-0512-9.

D. Behrend, C. Thomas, J. Gipson and E. Himwich, 2017. Planning of the continuous VLBI campaign 2017 (CONT17). In R. Haas and G. Elgered, (eds), *Proceedings of the 23rd European VLBI Group for Geodesy and Astrometry Working Meeting*, pages 132–135, Göteborg, Sweden.
URL http://www.oso.chalmers.se/evga/23_EVGA_2017_Gothenburg.pdf.

R. Heinkelmann, P. Willis, Z. Deng, G. Dick, T. Nilsson, B. Soja, F. Zus, J. Wickert and H. Schuh, 2016. Multi-technique comparison of atmospheric parameters at the DORIS co-location sites during CONT14. *Adv. Space Res.*, **58**, 2758–2773. doi: 10.1016/j.asr.2016.09.023.

M. Karbon, B. Soja, T. Nilsson, Z. Deng, R. Heinkelmann and H. Schuh, 2017. Earth orientation parameters from VLBI determined with a Kalman filter. *Geodesy and Geodynamics*, **8**(6) 396–407. doi: 10.1016/j.geog.2017.05.006.

D. MacMillan, 2017. EOP and scale from continuous VLBI observing: CONT campaigns to future VGOS networks. *J. Geodesy*, **91**(7), 819–829. doi: 10.1007/s00190-017-1003-4.

T. Nilsson, J. Böhm, M. Schindelegger and H. Schuh, 2012. High frequency Earth rotation parameters estimated from the CONT campaigns. In: D. Behrend and K.D. Baver, (eds), *Proceedings of IVS 2012 General Meeting*, NASA/CP-2012-217504, pages 390–394. URL http://ivscc.gsfc.nasa.gov/publications/gm2012/nilsson.pdf.

T. Nilsson, B. Soja, M. Karbon, R. Heinkelmann and H. Schuh, 2015. Application of Kalman filtering in VLBI data analysis. *Earth Planets Space*, **67**(136):1–9. doi: 10.1186/ s40623-015-0307-y.

G. Petit and B. Luzum, (eds). *IERS Conventions (2010)*. IERS Technical Note 36. Verlag des Bundesamts für Kartographie und Geod¨asie, Frankfurt am Main, Germany, 2010.

K. Teke, T. Nilsson, J. Böhm, T. Hobiger, P. Steigenberger, S. Garcia-Espada, R. Haas, and P. Willis, 2013. Troposphere delays from space geodetic techniques, water vapor radiometers, and numerical weather models over a series of continuous VLBI campaigns. *J. Geodesy*, **87**(10–12), 981–1001. doi: 10.1007/s00190-013-0662-z.