Organizing the Continuous VLBI Campaign 2017 (CONT17)

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Abstract The Continuous VLBI Campaign 2017 (CONT17) was observed from November 28 to December 12, 2017. Unlike previous CONT campaigns organized under the auspices of the IVS, CONT17 was not a single-network effort but featured three independent observing networks. Two legacy S/X networks of nominally 14 stations each observed in parallel for the full 15 days of the campaign. This was made possible in large part by the participation of the ten-station VLBA network of the LBO. Furthermore, for the five-day period from December 4-8, 2017 a six-station broadband network continuously recorded VGOS data. The different networks will help probe the accuracy of the VLBI estimates of the EOP and investigate possible network biases. In this paper, we describe the coordination effort undertaken to make CONT17 a successful endeavor. This includes the assignment of stations to the three networks based on EOP simulations, analysis of media, e-transfer, and correlation resources, as well as schedule writing, among other things.

Keywords CONT17, legacy S/X, VGOS, VLBA

1 Introduction

The Continuous VLBI Campaign 2017 (CONT17) is the continuation of a series of very successful continuous VLBI campaigns that have been organized and observed since 1994. For a more detailed summary of the various CONT efforts the reader is referred to [4]. A prominent feature of the CONT17 campaign was the utilization of three independent VLBI networks: two global legacy S/X networks and one northern hemisphere VGOS network. Having independently measured parameters for the same period enables us to get an estimate of their accuracy and to uncover possible biases originating from the station selection of the networks.

The CONT17 effort was an ambitious endeavor that necessitated the use of many resources. In this paper we try to touch on the organizational side of CONT17 and provide insights into the work of the Coordinating Center. This includes the preparatory work and the general handling of resources such as station observing time, correlator time, media usage, and data transport, among others.

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2 Some History

Prior to CONT17, five continuous VLBI campaigns were organized under the auspices of the IVS (i.e., after 1999) (see Table 1).

Table 1 History of CONT campaigns in the IVS era.

Campaign	Network size	Observation month	Observation length
CONT02	8 stations	Oct. 2002	15 days
CONT05	11 stations	Sept. 2005	15 days
CONT08	11 stations	Aug. 2008	15 days
CONT11	14 stations	Sept. 2011	15 days
CONT14	17 stations	May 2014	15 days

The network size increased significantly from 2002 to 2014, more than doubling the number of participat-

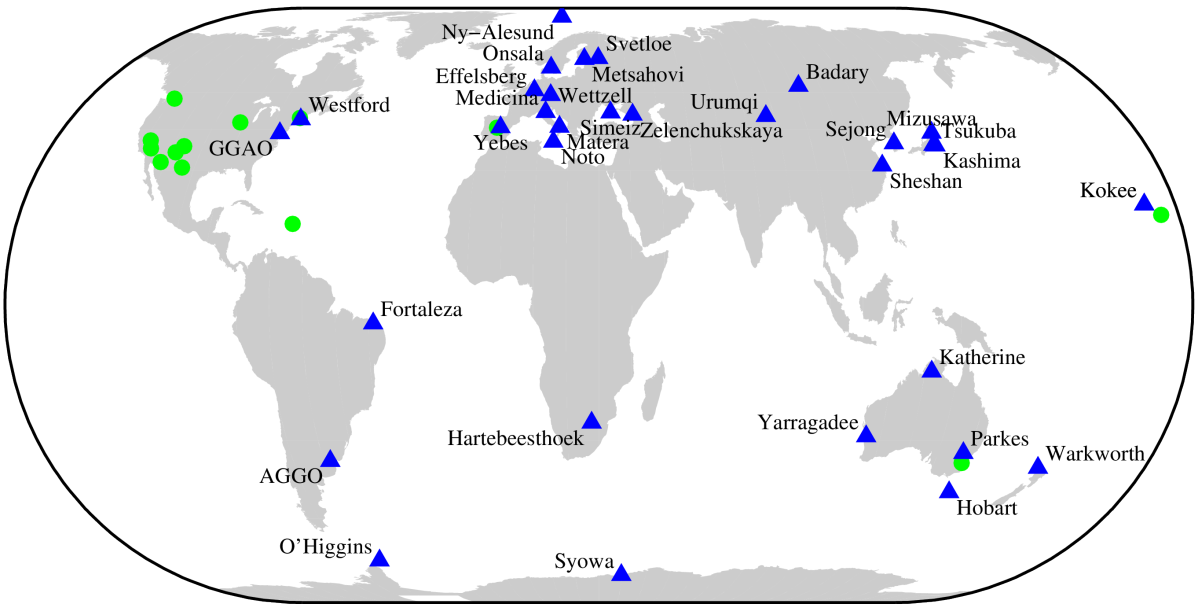

Fig. 1 Map of IVS Network Stations (blue triangles ▲) and cooperating VLBI sites (green circles ●) as of 2016. These 42 stations constituted the available station pool that might participate in the CONT17 effort as of that time.

ing stations. Most of the campaigns were observed in the second half of the calendar year (the sole exception being CONT14), and all CONTs took data for 15 days.

The spacing between the CONT campaigns is roughly three years. The reason for this can be traced back to a decision by the Observing Program Committee (OPC) in 2005. CONT campaigns should not be observed more frequently than every three years, because the strain on the resources (mostly stations and correlators) was considered too taxing. This, of course, holds for the legacy S/X stations; but it also puts into perspective the VGOS goal of 24/7/365 continuous observing in the future. Following the three-year rule, the next CONT campaign would be in the year 2020.

The first actual mention of a CONT17 campaign was made at the IVS General Meeting in Shanghai, China in 2014 (see, e.g., [1]), with two possible scenarios mentioned:

- to observe a campaign with a legacy S/X network in parallel to a VGOS network;
- to observe a campaign with a mixed network of legacy S/X and VGOS stations.

The implementation of either would depend on the station availability and thus also on the observing time frame.

3 Observing Period

Serious discussion about CONT17 commenced in early 2016. The Coordinating Center internally discussed the possible time frame for the campaign and decided on late 2017 (or early 2018). In April 2016, CONT17 was on the agenda of an OPC meeting for the first time. Then the Coordinating Center contacted various VLBI groups (e.g., EVN, GMVA, JIVE) to determine a time period with the least conflict potential. Based on these discussions the actual observing period was fixed to November 28 – December 12, 2017.

4 Station and Correlation Resources

The discussions about the time frame triggered interest in the Very Large Baseline Array (VLBA) being part of the CONT17 effort. The VLBA was being reorganized at the time to be managed by the Long Baseline Observatory (LBO) starting 1 October 2016; hence, the actual inclusion procedure was still unclear.

The Coordinating Center sent out the Call for Participation in CONT17 to the stations in June 2016 together with the station time request for the Master

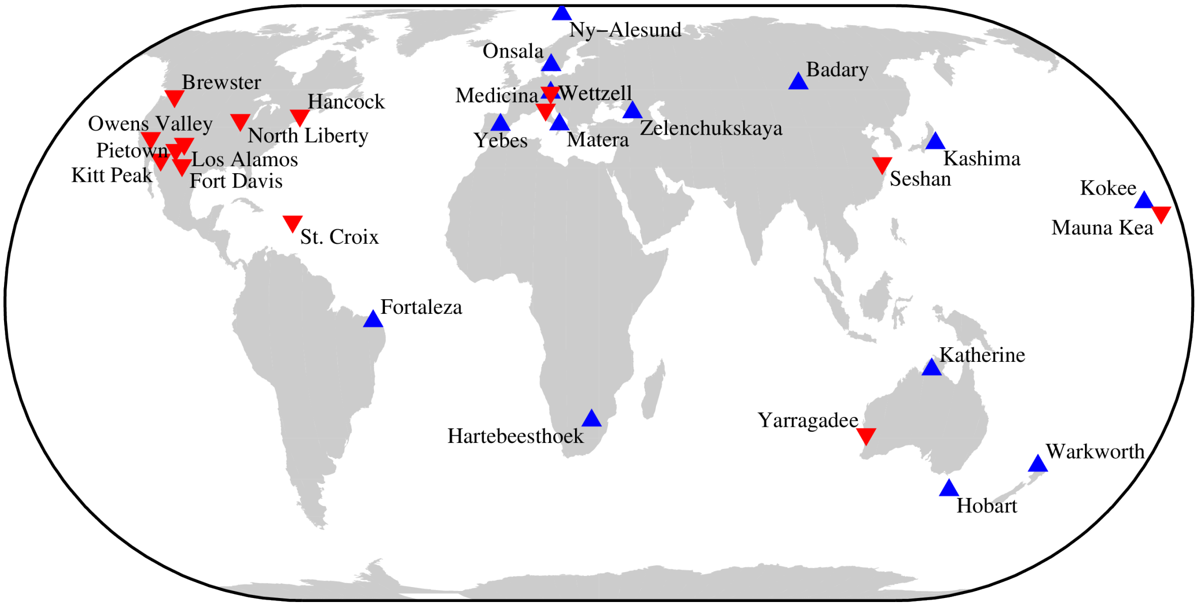

Fig. 2 The two legacy S/X networks of CONT17: the Legacy-1 network is depicted by blue triangles ▲ and the Legacy-2 network by red inverted triangles ▼. Twenty-seven stations at 26 sites participated in the S/X portion of CONT17.

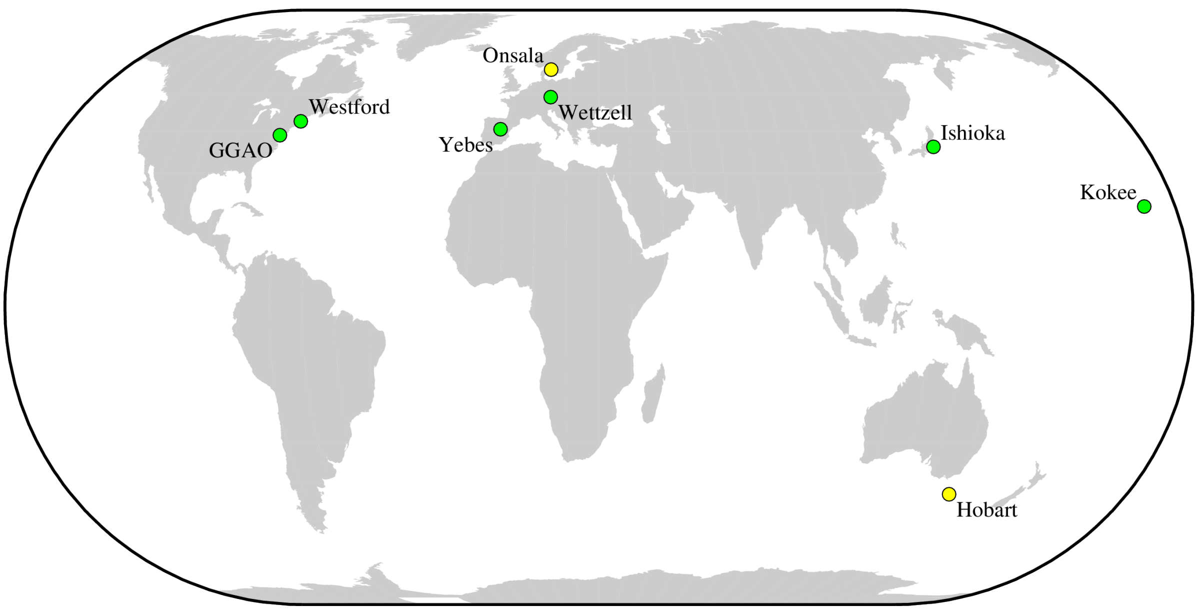

Fig. 3 The six-station VGOS demonstration network (VGOS-Demo, green circles ●) of CONT17. The broadband signal chain roll-out for Onsala and Hobart (yellow circles ●) was not completed on time for an official inclusion in the campaign.

Schedule 2017. In response, some 19 IVS Network Stations (S/X and VGOS) agreed to participate. The participation of the VLBA had to be requested through a proposal to the USNO VLBA Telescope Allocation Committee (TAC). The GSFC VLBI Group made several EOP simulations with varying networks, setups, and parameters/options. A proposal "Using the VLBA in CONT17 as a probe of the accuracy of VLBI estimates of EOP" was submitted to the TAC in late December 2016 and approved about a month later. With the approval of the proposal, the decision was made to have two legacy S/X networks and one VGOS network for CONT17.

The plans for CONT17 were presented at the EVGA meeting in Gothenburg, Sweden in May 2017. As a consequence, two additional stations (Kashima and Seshan) requested to be added to the networks. Following several additional simulations, the final networks were determined as depicted in Figures 2 and 3. Thus, by mid-2017 the observing networks, consisting of two legacy S/X networks of nominally 14 stations each and one VGOS broadband network of up to eight stations, as well as the observing period were settled.

Three correlators were involved in the bulk of the CONT17 processing (cf. Table 2). In addition, the Washington Correlator assisted by reducing the work load on the Bonn Correlator prior to and after CONT17, taking over the correlation of regular IVS sessions (e.g., R1 sessions) from mid-November 2017 through the end of April 2018.

Table 2 Data rates and correlators of the CONT17 networks.

Network	#stations	Data rate	Correlator	Comment
Legacy-1	14	512 Mbps	Bonn	—
Legacy-2	14	256 Mbps	Socorro	VLBA
VGOS-Demo	6	8 Gbps	Haystack	—

The limitations of the media pool, e-transfer capacities, and data storage (at the correlators) largely determined which data rates were possible for the observing networks. The Legacy-1 network used the same mode as was used in CONT14, that is, a 512-Mbps mode. For Legacy-2, a 256-Mbps recording mode was chosen; while a 2-Gbps mode similar to the VCS-II survey would have been possible for the VLBA stations, this mode was too risky for the four geodetic stations. The observing mode for the VGOS network was identical to the one used for the VGOS test sessions.

Table 3 Data storage and data transport resources.

Network	e-transfer	Module shipment	Storage type	Volume per day
Legacy-1	12 stations	Matera, Kokee	Mark 5, FlexBuff	40.6 TB
Legacy-2	—	all stations	Mark 5	23.8 TB
VGOS-Demo	Ishioka	five stations	Mark 6	132 TB

The Bonn Correlator arranged to have 600 TB of storage space available for the Legacy-1 network. A contingency RAID was built using eight 32-TB Mark 6 modules. In this setup, Bonn was able to support twelve stations with e-transfer of data; two stations had to ship their Mark 5 modules physically (see Table 3). All stations of the Legacy-2 network had to ship their modules physically to Socorro. For the VGOS-Demo, only one out of the six stations e-transferred their data to Haystack.

5 Schedule Writing and Source Selection

The individual observing schedules were written using NASA's scheduling software *sked* [3]. The schedulers for each network as well as some general features are compiled in Table 4; there were altogether four schedulers involved. For the legacy S/X schedules the observing was organized in 24-hour time periods from 0–24 UT. This was done to be compatible with the other space-geodetic techniques.

Table 4 Preparation of observation schedules.

Network	Scheduler	Change-over time	General technique
Legacy-1	Dirk Behrend, Cynthia Thomas	3 min	complete period, then cut into days
Legacy-2	David Gordon	5 min	individual days
VGOS-Demo	Alex Burns	15 min	individual days

From the full 24 hours the schedule changeover time needs to be subtracted. That means that, for instance, the Legacy-1 network had no more observations after 23:57:00 UT of each day (except for the final day). To eliminate operational difficulties at stations with both legacy S/X and VGOS antennas, the VGOS sessions started at 23 UT, one hour before the S/X sessions. The last day of the VGOS-Demo portion was then scheduled for 25 hours. Hence, in the processing stage it would be possible to rearrange the data to the 0–24 UT time span.

For the scheduling of the Legacy-1 network the same scheme was employed as for CONT14 (see [2]). The full 15 days of CONT17 were written in a single schedule file (with gaps of three minutes at the end of each UT day); then this file was broken up into individual observing days. Because the cable-wrap information was carried forward across the day boundaries, this allowed very brief changeover times (necessary for changing schedules at the stations). The Legacy-2 and VGOS-Demo schedules were written as independent single days.

As the observation of the Intensive sessions for UT1 determination had precedence over the CONT17 observing, stations participating in Intensives were removed from the CONT17 observations during Int1, Int2, and Ru-I Intensives. No Int3 Intensive was observed during CONT17. As the VLBA Intensives are dynamically scheduled, no slots were freed in the Legacy-2 network, and the loss of observations was simply accepted.

The final list of sources used for scheduling contained 92 sources. The source selection was the work of Karine Le Bail and was done by applying three criteria:

- Flux values $\geq$ 0.25 Jy in S- and X-band (August 2017 flux values);
- Failure rate in 2017 $\leq$ 20% in S- and X-band;
- Structure index (SI) better than 3.

This resulted in a list of 142 sources. From this list the best 90 sources were selected using *sked*'s BEST-SOURCE command. Finally, two southern sources were added back manually for better sky coverage; they had a failure rate of 24% in 2017.

6 Preliminary EOP Results

As part of the resource allocation process described in Section 4, a number of simulation runs using the *Solve* software were done to determine the optimal networks. Table 5 summarizes the EOP formal errors for the three CONT17 networks plus the results using the actual data for CONT11 and CONT14 (using the same control file in *Solve*). Note that no station velocities were estimated, and thus the results are too optimistic. But the intrinsic measurement precision is represented correctly, allowing intercomparison of the results from the different networks and different times. Behrend et al. (2014) explains in more detail the impact of estimating station velocities in the covariance simulations [1] .

Hence, from the simulations it was expected that the CONT17 legacy S/X networks would have similar EOP formal errors as CONT11, which also sported a

Table 5 Simulated EOP formal errors derived from a covariance analysis without station velocity estimation for the three CONT17 networks and the actual data for CONT11 and CONT14.

Network	#stat	σ_{Xpole} [µas]	σ_{Ypole} [µas]	σ_{UT1} [µs]	σ_{ψ} [µas]	σ_{ε} [µas]
Legacy-1	14	13.0	13.7	0.9	14.4	13.1
Legacy-2	14	15.0	17.5	0.8	15.0	14.3
VGOS-Demo	8	22.1	22.5	0.8	17.2	18.1
CONT11	14	12.9	13.1	0.7	13.4	13.8
CONT14	17	12.6	12.3	0.7	14.2	13.2

14-station network of global extent. As the simulated data represented the ideal case of 100% successful observing, the final results were anticipated to be slightly worse depending on the level of missed observations.

The slightly inferior EOP formal errors for the VGOS-Demo network are mostly due to the limited geographic range of this network. As the simulation was done with the originally planned eight-station network (including Onsala and Hobart), the actual EOP formal errors for the VGOS portion of CONT17 will be higher.

Two stations dropped from the original VGOS-Demo network. The VLBA station of St. Croix was not available for the Legacy-2 network because of the aftermath of Hurricane Maria. Furthermore, Seshan had a failure about mid-way through observing the campaign and thus missed the second half of CONT17.

The data transport and correlation of the CONT17 legacy S/X data was quite fast. The elapsed time from the end of the last observation to having all CONT17 data correlated took about 77 days for Legacy-1 and some 21 days for Legacy-2. This compares to 138 days for CONT11 and 51 days for CONT14. The jump in processing speed from 2011 to 2014 can largely be attributed to the changeover from hardware correlator to software correlator. The (relative) increase of the elapsed time from CONT14 to CONT17 Legacy-1 is an indication of still remaning bottlenecks in the e-transfer of data.

Based on a Goddard solution (2016a) but without estimating station velocities, Figure 4 shows the EOP uncertainties for the continuous VLBI campaigns since 2002. As for the simulation results, the formal errors are too optimistic but they are intercomparable between the campaigns. (More realistic numbers for the actual accuracy may be obtained by multiplying with a factor between 1.5 and 1.8 depending on the distance

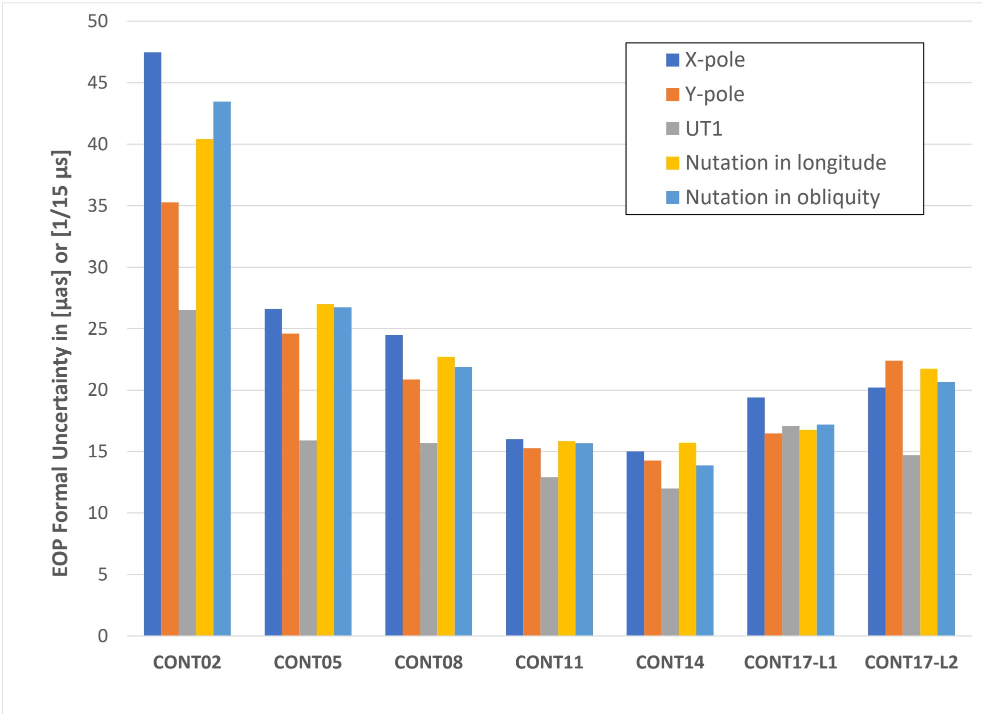

Fig. 4 EOP uncertainties for the CONT campaigns since 2002 based on a Goddard solution (2016a) with no station velocity estimation.

from the midpoint of the overall data span.) The actual, unscaled EOP formal errors are in reasonable agreement with the simulation results. The actual Legacy-1 EOP uncertainties are marginally worse than found in the simulation; this can easily be explained by the loss of observations. Likewise, the slightly worse performance of Legacy-2 is a direct result of the decrease in the number of observations and the geographic coverage (i.e., loss of the VLBA station at St. Croix).

The overall best continuous VLBI campaign in terms of formal errors is CONT14. This comes as no surprise, as it had the largest network size (17 stations) and best geographic distribution. CONT11 is only slightly worse with its 14-station network. As the CONT17 Legacy-1 and Legacy-2 networks were formed as a compromise to define two global networks, their performance did not reach the level of CONT11. But they performed better than the CONT02, CONT05, and CONT08 networks, which had a weaker global distribution and size.

The early results for the Legacy-1 and Legacy-2 networks indicate that the two networks are consistent with each other at the 1.5-sigma level. That is, there is likely no bias between larger global networks. This needs to be looked at in more detail.

7 Acknowledgement in Publications

It is essential that contributors to the success of CONT17 be acknowledged in publications that make use of CONT17 data. An acknowledgement to this effect assists the VLBI components in securing continued funding for their activities. The IVS Directing Board, thus, established a data policy for CONT17 that includes a request to add a specific acknowledgement text to CONT17 publications. The text is available at the CONT17 Web page at `https://ivscc.gsfc.nasa.gov/program/cont17/` and is also included at the end of this paper as the acknowledgements section.

The availability of the CONT17 data is initially restricted. For a period of six months after the completion of the correlation the full set of CONT17 session days is only accessible to involved parties. Following the half-year data embargo period, the CONT17 data fully become publicly available through the IVS Data Centers.

8 Conclusions and Outlook

The preparation of the CONT17 campaign started as early as Feburary/March 2016, i.e., more than 1.5 years prior to the actual observing. It is the first continuous VLBI campaign that made use of three different networks. The independent networks allow probing of the accuracy of the EOP estimates, in particular of UT1 and nutation. During the IVS era, CONT17 was the first continuous VLBI campaign that included the VLBA.

It seems likely that CONT17 will remain the largest legacy S/X CONT effort, as stations start to convert to the VGOS system (e.g., the AuScope antennas at Hobart, Katherine, and Yarragadee). Prior to the complete changeover to the VGOS, a final CONT campaign in 2020 (CONT20) could be organized that will be based on a mixed network of S/X and VGOS stations. Once VGOS is operational, continuous VLBI observing will be the standard mode of operations.

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