JUMPING JIVE

Project ID: 730884

Analysis of EVN station positions

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Contents

List of Acronyms

CODE	Center for Orbit Determination in Europe
EOP	Earth Orientation Parameters
EVN	European VLBI Network
HOPS	Haystack Observatory Post processing System
ICRF	International Celestial Reference Frame
ITRF	International Terrestrial Reference Frame
IVS	International VLBI Service for Geodesy and Astrometry
Mk4	Mark 4 data-acquisition and correlation system
SFXC	EVN Software Correlator developed at JIVE
TOTMBD	Total Multiband Delay
VGOS	VLBI Global Observing System
vgosDB	vgos Data Base

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1. Introduction

The European VLBI Network (EVN) includes telescopes that participate regularly in dual-frequency (S- and X-band) geodetic campaigns, generally organized by the International VLBI Service for geodesy and astrometry (IVS), and thus have highly accurate geodetic positions. But it also has other telescopes not equipped with S/X radio receivers, which have never participated in such campaigns and thereby have less accurate positions. The telescopes in the latter category are located at Jodrell Bank (United Kingdom), Sardinia (Italy), Torun (Poland) and Westerbork (Netherlands). Also comprised in this category are the three Korean VLBI Network (KVN) telescopes in Yonsei, Ulsan and Tamna. Inaccuracy in telescope positions can limit severely the outcome of observations conducted with the phase-referencing technique, a technique routinely used to image weak radio sources with the EVN and which requires accurate knowledge of the full VLBI geometrical model (e.g. source coordinates, Earth orientation, telescope coordinates) to perform well (Beasley et al. 1995, Charlot et al. 2001).

In order to derive geodetic products, like telescope positions, a VLBI correlator must be able to properly handle geodetic sessions which are scheduled with sub-netting. It must also be capable to export the data in Mk4 format for the subsequent fringe-fitting process to compute the delay and delay rate measurements. All these steps, which refer to what we generally call the geodetic path, were already implemented as part of the work previously carried out for this work package, the details of which may be found in Deliverables 6.1 and 6.2.

In the following, we describe the scheduling, correlation, post-processing and geodetic analysis for the EVN experiment EC065, which was carried out in June 2018 with the purpose of providing coordinates for the non-geodetic EVN telescopes in Jodrell Bank (Jodrell Mark 2 antenna, hereafter abbreviated to Jodrell2), Torun, Sardinia and the KVN stations.

Geodetic positions with 5 cm accuracy were first determined by Charlot et al. (2001) for two of these telescopes, Jodrell2 and Torun, from a dedicated experiment run by the EVN in November 2000 (TP001). Two decades have passed since then, hence making it possible to estimate the velocity of Jodrell2 and Torun by comparing the results of TP001 and EC065.

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2. Implementation

2.1. Design of the experiment (scheduling)

The purpose of the EC065 experiment was to measure the position of non-geodetic EVN telescopes by carrying out an experiment similar to TP001, but now with more non-geodetic telescopes participating. The targeted telescopes were not only Jodrell2 and Torun but also the Sardinia Radio Telescope and the three Korean stations. We requested all EVN telescopes with observing capability at 22 GHz to be included in order to tie the observing network to the ITRF2014 terrestrial reference frame.

The experiment, which lasted 24 hours, took place on 13-14 June 2018 and comprised the following 20 antennas:

Badary (Bd), Effelsberg (Ef), Hartebeesthoek (Hh), Jodrell2 (Jb), KVN-Yonsei (Ky), KVN-Tamna (Kt), KVN-Ulsan (Ku), Medicina (Mc), Metsähovi (Mh), Noto (Nt), Onsala60 (O6), Sardinia (Sr), Svetloe (Sv), Torun (Tr), Yebes40m (Ys), Zelenchukskaya (Zc) and the four e-MERLIN out-stations capable of observing at 22 GHz (Cambridge, Darnhall, Knockin, Pickmere).

While standard geodetic sessions, e.g. within the IVS, are conducted at S/X band to allow for the calibration of ionospheric delays, this observing mode was not a possibility for EC065 because the non-geodetic EVN antennas are not equipped with such dual-frequency receivers. Additionally, the KVN telescopes can observe only at high frequency. As a result, the EC065 experiment was run at 22 GHz.

As for TP001, a specific bandwidth synthesis scheme was designed for the observations. The common frequency range between all EVN telescope receivers at 22 GHz was found to be approximately 400 MHz. With this frequency range, it was possible to implement a setup consisting of 8 tunable LSB/USB pairs of frequency channels (use of LSB/USB pairs is driven by the KVN stations) spread over 360 MHz, as in former geodesy experiments.

A recording rate of 512 Mb/s was considered enough for our purposes taking into account the large dishes that are comprised in the network.

The scheduling was carried out by means of the NASA SKED program, optimizing the sky coverage above each telescope. A total of 62 extragalactic radio sources picked up from the ICRF3 at K-band (Charlot et al. 2020), well spread in right ascension and with declination between -45° and 90°, were selected. Integration time was adjusted separately for each scan and each telescope so that high signal to noise ratios can be obtained.

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2.2. Correlation and post-processing

The correlation was carried out with the SFXC (the EVN software correlator at JIVE) using its new geodetic capability. This also means that the correlator output was exported to the Mk4 format which is the standard input for the HOPS software used for post-processing the data.

HOPS 3.20 was used and manual phase-cal was applied for most of the stations due to the absence or weakness of the phase-cal tones. Figure 1 shows the typical HOPS output after fringe-fitting a scan for the baseline Sardinia-Torun. As shown in the figure, it was possible to detect the signal and adjust the phase in order to estimate the Total Multiband delay (TOTMBD) as well as the delay rate (represented as the blue and red lines at the top of the plot).

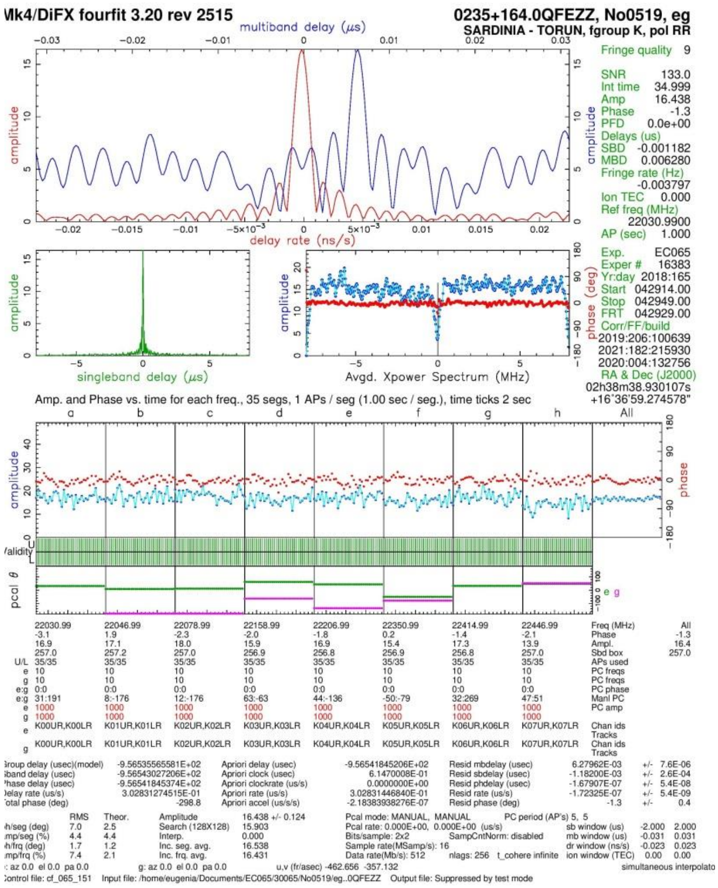

Figure 1. Fringe-plot obtained for one of the scans on the baseline Sardinia-Torun during the EC065 experiment.

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After fringe-fitting, the data were exported into VGOS database format (vgosDB) which is the standard format for geodetic data. This was done by using nuSolvev.0.6.4, the software used by the geodetic community to produce such a format. We further used nuSolve to estimate clocks, clock breaks, and ambiguities and to create version 4 of the database.

2.3. Analysis and Results

A total of 14 out of the 20 scheduled telescopes provided observations whose data were able to proceed successfully through all stages of the geodetic analysis (see Figure 2). Unfortunately, two of the Korean telescopes (Ku and Kt) failed to participate in the observations (and Ky joined for only 12 of the 24 hours). The e-MERLIN out-stations applied fibre-delay corrections directly into their data prior to sampling and recording, which amounted to delay jumps at times that were not possible to reconstruct a posteriori. The presence of such jumps in EC065 prevented reliable computation of TOTMBDs for those stations (note that the insertion of these fibre-delay corrections can now be turned off during VLBI observations).

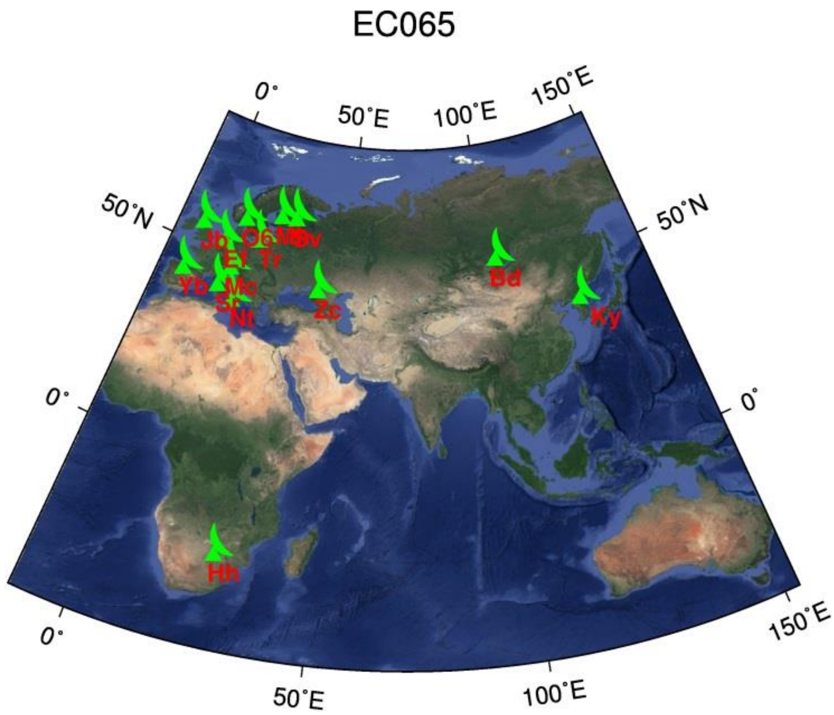

Figure 2. Distribution of the telescopes involved in the EC065 experiment

During the experiment, 62 ICRF3 sources (among which 28 defining) were observed in a total of 478 scans over the 24-hour duration of the experiment.

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The geodetic analysis was carried out with the Vienna VLBI software package, VieVS (Böhm et al., 2018), based on the modeling presented in Table1. After trying JPL and CODE ionospheric maps, the latter was selected to model the ionospheric delay contribution. The selection was done after checking the statistics that showed a slightly better RMS and Chi-square for the CODE solution.

Table 1. Overview of the models used in the analysis of the EC065 data.

Data/Models	Comments
Ephemeris	JPL421
Earth Orientation Parameters	IERS C04
Terrestrial Reference Frame	ITRF2014
Celestial Reference Frame	ICRF3(K)
Ocean Tide Loading	FES2004
Ionospheric correction	CODE
Galactic Acceleration	YES
Tropospheric hydrostatic model	Saastamoinen
Tidal atmospheric loading	Vienna
Non-tidal atmospheric loading	Vienna
Tropospheric Mapping function	VMF3

The datum was defined by not-net-rotation and no-net-translation constraints with respect to ITRF2014. Source coordinates were treated as fixed, while station coordinates and EOP were estimated together with clocks and tropospheric parameters. The last three were estimated as piecewise linear functions with a time interval of 24 hours for EOP (relative constraint of 0.1 mas), 30 minutes for the zenith wet delay (relative constraint of 1.5 cm) and 60 minutes for the clock interval (relative constraint of 1.3 cm). In this case, we considered one rate and one quadratic term per clock.

Figure 3 shows the delay residuals per station. The weighted RMS is about 1 cm for both the geodetic and non-geodetic telescopes, with the lowest residuals belonging to the biggest antennas (Effelsberg, Sardinia, Yebes40m). The estimated coordinates of Jodrell2, Torun, Sardinia and KVN-Yonsei are given in Table 2.

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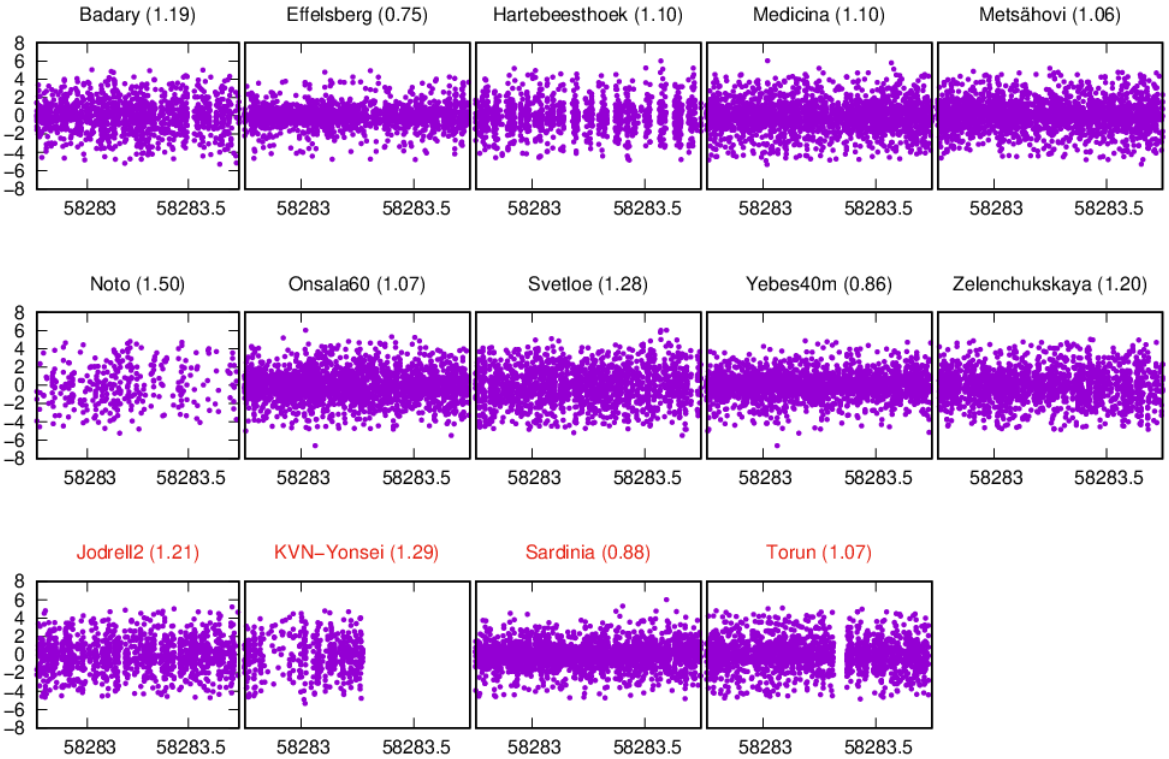

Figure 3. Post-fit residuals per station in cm and weighted RMS in parenthesis. Each point represents an observation on a baseline that includes the mentioned station.

Table 2. Coordinates estimated for the Jodrell2, Torun, Sardinia, and KVN-Yonsei telescopes based on the data of EC065.

	ITRF2014 (t2018.449) coordinates and formal errors					
Station/Coords.	X [m]	Y [m]	Z[m]	σ_x [m]	σ_y [m]	σ_z [m]
Jodrell2	3822846.497	-153801.919	5086286.153	0.008	0.003	0.010
Torun	3638558.154	1221970.072	5077036.942	0.004	0.002	0.005
Sardinia	4865183.223	791922.558	4035136.164	0.004	0.002	0.004
KVN-Yonsei	-3042281.101	4045902.599	3867374.270	0.009	0.013	0.014

Comparison with TP001

The comparison between TP001 and EC065 coordinates for the antennas having position determinations in both experiments (Torun and Jodrell2) was accomplished in two ways: (i) directly at the same epoch after transforming the TP001 coordinates into ITRF2014 and (ii) by estimating the velocity for Jodrell2 and Torun.

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Before comparing the coordinates obtained from EC065 and TP001 it was mandatory to transform the TP001 coordinates from ITRF2000 to ITRF2014. The transformation was done following the procedure and transformation parameters given on the ITRF web page (*http://itrf.ensg.ign.fr/doc_ITRF/Transfo-ITRF2014_ITRFs.txt*) and by applying ITRF velocities from nearby sites obtained with the UNAVCO plate motion calculator (www.unavco.org).

As indicated in Table 3, the agreement is at the 1-3 cm level, which is very satisfactory considering that the TP001 position accuracy was estimated to be on the order of 5 cm.

Table 3. Differences between the TP001 and EC065 coordinates for Jodrell2 and Torun at epoch 2018.45, as expressed in the ITRF2014 reference frame.

	differences w.r.t. TP001 in ITRF2014 (t2018.449)		
Station	DX [m]	DY[m]	DZ [m]
JODRELL2	0.004	0.009	0.033
TORUN	0.019	0.018	-0.014

Once transformed into ITRF2014, but without changing epoch, the TP001 coordinates may also be used to estimate the components of the displacements after almost 20 years by comparison with the EC065 coordinates (Figure 4). The magnitude of the displacements, 25-30 mm/yr, is in agreement with the motions derived from plate tectonic models for Europe.

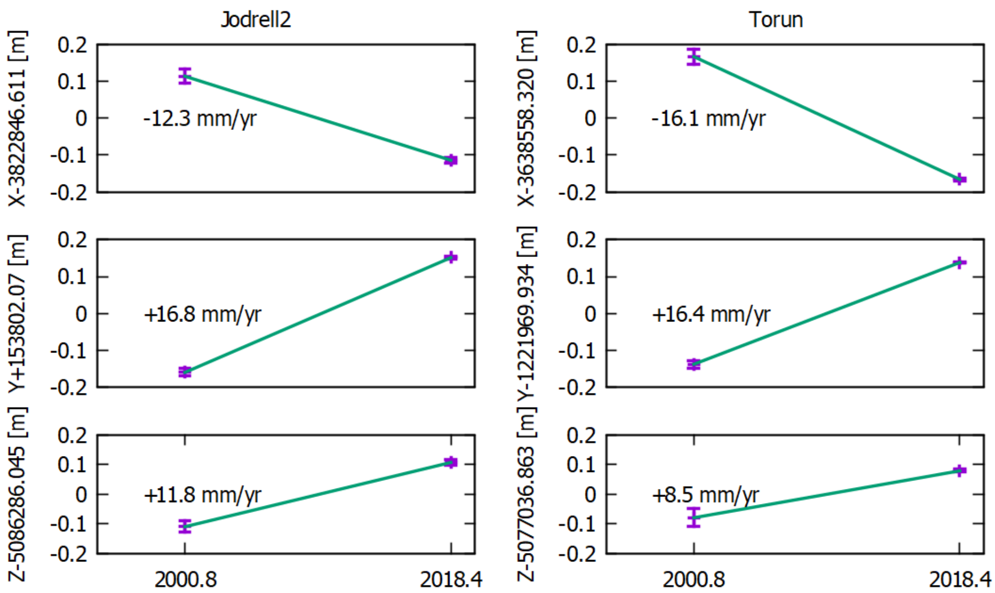

Figure 4. Displacements and velocity components estimated for Jodrell2 (left) and Torun (right).

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3. Conclusions

A K-band geodetic-type experiment was designed and run on the EVN to derive coordinates of the non-geodetic antennas. This experiment was correlated with the EVN software correlator at JIVE, post-processed and analyzed via standard geodetic-VLBI techniques. This demonstrates the validity of the preceding accomplishments within this Work Package to develop the geodetic path within JIVE.

The coordinates estimated from this experiment are at the 1 cm level and are in agreement with those derived from a previous EVN experiment carried out 20 years ago that was correlated in Bonn. The improved empirical station velocities for non-geodetic EVN telescopes will replace model-based ones that are currently used in scheduling/correlation catalogs, and thus will bring benefits to phase-referencing observations throughout the EVN.

We expect to take these results further by adding the data from another K-band experiment that was conducted in October 2020.

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