A Strategic Independent Geodetic VLBI Network for Europe

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Abstract Irregularities of the rotation of the Earth in space are described by the Earth Orientation Parameters (EOPs). An independent EOP network, applying the Very Long Baseline Interferometry (VLBI) technique and using the Vienna VLBI Software (VieVS), are strategically essential for Europe to minimize its reliance on foreign global support in terms of required infrastructure for the realization of such a network. The generation of independent EOPs is already achievable by countries such as the USA, the People's Republic of China, and the Russian Federation due to their large extent of land mass that allows for long baselines in both the North-South and East-West directions and thus allows for accurate determination of all EOPs. These three countries need not rely on foreign partnerships to generate EOPs, as they all have independent geodetic VLBI networks capable of determining EOPs for precise positioning, navigation, and satellite launch/orbital purposes. They also have or are developing independent Global Navigation Satellite Systems (GNSS) constellations; so does the European Union (EU). Accurate EOPs are essential for long-term orbital maintenance of GNSS constellations, leaving the EU GALILEO GNSS vulnerable and reliant on the three superpowers. Generation of accurate EOPs by Europe is not possible due to its much smaller land mass and thus smaller achievable baselines. Even though there are many radio telescopes spread across Europe, these are separated by relatively short distances. The proposed stations that will be used to investigate this independent EOP network for Europe are the WETTZELL radio telescope in Germany, two German owned radio telescopes, TIGOCONC in Concepción, Chile, and OHIGGINS in Antarctica, as well as the HartRAO radio telescope in South Africa.

Keywords Independent European EOP network, VLBI, Earth Orientation Parameters, VieVS, GALILEO

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1 Introduction

The Very Long Baseline Interferometry (VLBI) technique and equipment are currently in a period of upgrade and modernization (Schuh and Böhm, 2013). The use of VLBI has seen rapid extension for the past three decades and has gained widespread recognition (Clark, 2003). The ground-breaking precision and resolution made possible by VLBI has provided substantive contributions not only to astronomy but also to the areas of geodesy, astrometry, and spacecraft tracking. The VLBI technique is unique in that it provides milliarcsecond (mas) or even sub-milliarcsecond resolution of astronomical radio sources and allows us to measure the positions of radio sources with sub-milliarcsecond accuracy (Walker, 1999), (Thompson et al., 2007). Accurate positions of extragalactic radio sources, made possible by VLBI measurements, currently define and maintain the International Celestial Reference Frame (ICRF). Geodetic VLBI observations of extra-galactic reference sources (quasars) are used to measure the positions of participating antennas separated across continents to mm precision. The technique is also the most accurate method in both astrometry and geodesy (Sovers et al., 1998). In addi-

tion, several geodynamic, atmospheric, and astronomical parameters can be derived from the long history of VLBI measurements, which commenced in the late 1970s. Only geodetic VLBI provides the link (the Earth Orientation Parameters, or EOPs) between the ICRF and the ITRF. The EOPs provide the Earth's orientation in inertial space at a given epoch and need to be measured continuously. Furthermore, VLBI is the only technique that provides the full set of EOPs, which are indispensable for positioning and navigation on Earth and in space.

Precise tracking of satellites for Earth monitoring, gravity field and other studies (Satellite Laser Ranging (SLR)), laser ranging for studying lunar motion (Lunar Laser Ranging (LLR)), long-baseline radio interferometric observations for deciphering extra-galactic radio sources (VLBI) and the precise manoeuvring of interplanetary flights all require a precise measurement of the motions of the Earth's rotation axis. At the same time, these different geodetic observational techniques such as SLR, LLR, GNSS, and Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS) contribute to the generation of EOPs. However, only geodetic VLBI permits the changes in rotation to be measured with an unprecedented precision and resolution (Lambeck, 1988). The other geodetic systems are Earth-centered, whereas VLBI relies on the fixed positions of selected extra-galactic radio sources, which create an absolute and fixed reference frame. These measurements are crucial for the determination of Earth orientation with respect to inertial space and to the ITRF, which is a precondition for long-term monitoring, and they are crucial for the determination of other geodetic parameters, for Earth studies, including the maintenance of the ITRF and the ICRF.

The importance of determining EOPs is critically linked to the maintenance of the accuracy of GNSS orbits upon which much of the world depends for navigation in space and locating positions on Earth. Furthermore it is also essential for satellite orbit determination and spacecraft navigation, as well as deciding to insert or delete leap seconds in the UTC, which is the primary time standard by which the world regulates clocks. The EOPs are also used to obtain positions and velocities of radio antennas that define a VLBI-based ITRF, and lastly to accurately determine the geometric delay of observations in astronomy and astrometry. Providing the basis for precise positioning and navigation, geodesy is also crucial for supporting or enabling many activities and processes in a modern society.

2 Surveys and Experiments

Geodesy provides the foundation for most Earth observations as well as crucial observations of changes in the Earth's geometry, gravity field, and rotation, which are all related to mass transport in the Earth system and system dynamics. Thus, it is driven to meet many requirements of observations of global changes and observations supporting studies of the Earth system. The International VLBI Service for Geodesy and Astrometry (IVS) is an international collaboration of organizations which operate and support geodetic and astrometric VLBI work on reference systems and Earth science research in general and provides the basis for all operational activities. The geodetic VLBI data products currently available are the full set of EOPs, the TRF, the CRF, and tropospheric parameters. These are provided on a regular basis by the IVS and stem from a continuous program. The IVS currently has more than 30 network stations across the globe and is roughly supported by 40 institutions in 20 countries (Figure 1). Global participation in VLBI observations is required to obtain accurate EOPs.

To accurately determine EOPs with VLBI, very long North-South and East-West baselines between antennas are needed. North-South baselines are most sensitive to polar motion, and the East-West baselines are most sensitive to UT1 (Schuh, 2000). It is therefore crucial to include stations in high and low latitudes if pole coordinates are to be estimated with the highest accuracy. The proposed stations to be used for the independent EOP European network research are indicated in Figure 1. Covering the period from 2003 to 2014, 13 existing T2 sessions were utilized. All stations were used in the processing of the sessions. Consequently a subset of stations using only the proposed EU strategic network were then processed, to test the stability and the accuracy of the EOPs for the proposed network relative to the larger network.

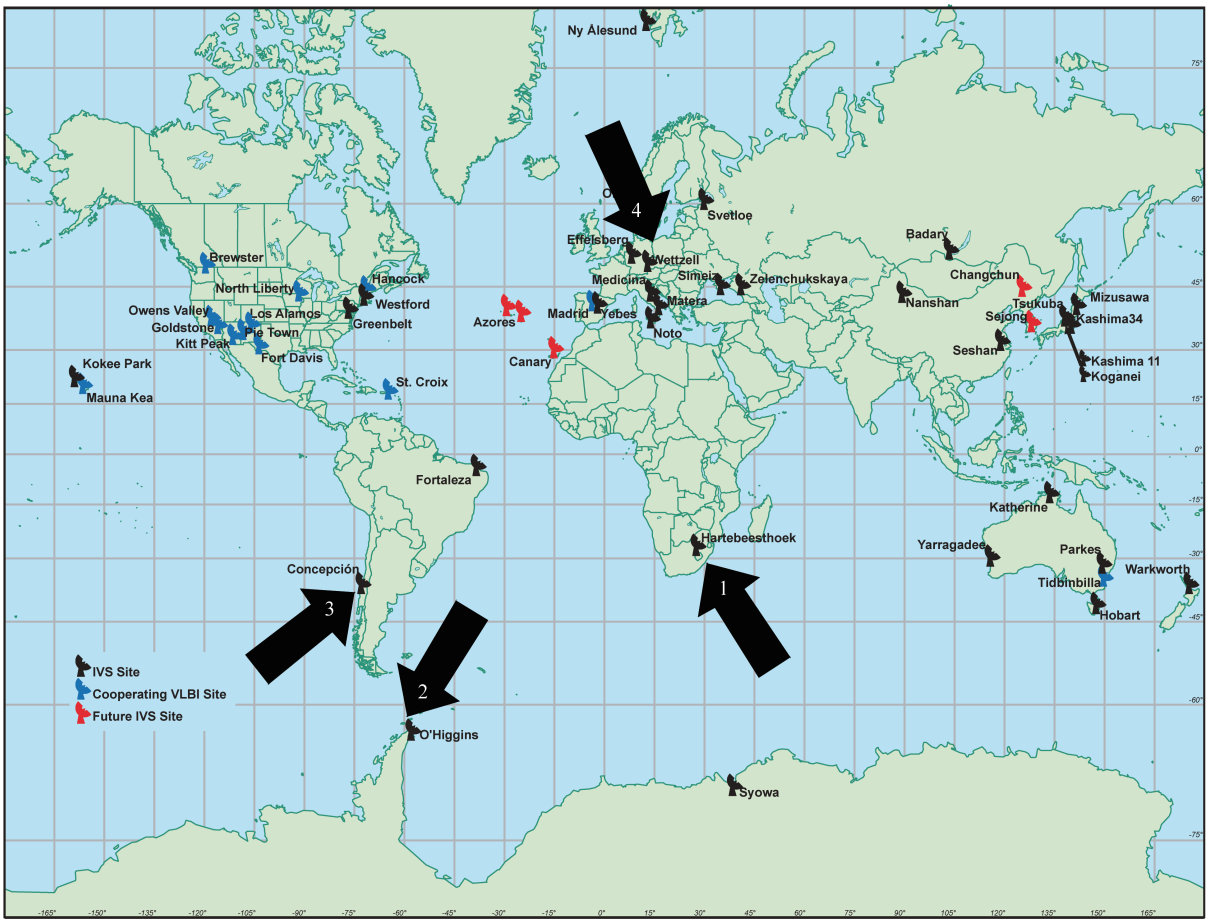

Fig. 1 World map illustrating the stations participating in the current international geodetic networks. Arrows show the proposed stations for investigating the independent EOP network for Europe: the HartRAO radio telescope in South Africa (1), OHIGGINS in Antarctica (2), TIGOCONC in Concepción, Chile (3), and WETTZELL in Germany (4).

3 Data Reduction

The VieVS software, developed by the Department of Geodesy and Geoinformation, of the Vienna University of Technology, is a MATLAB based program with an easy to use Graphical User Interface (GUI) (Böhm et al., 2012). This software is used for data analysis and evaluation of alternative strategies and network configurations. Network configurations will be changed to evaluate the impact of network density, data quality and quantity and baseline length. From the T2 sessions, the 2008 T2053 was chosen as the first session for preliminary EOP analysis. The T2053 session has 11 stations in total that participated in observations, including the proposed EU EOP network stations. The EOP results were obtained for the whole network and then for the proposed EU EOP network stations only. These results are listed in Table 1.

4 Preliminary Results

To evaluate the EOP results we obtained, a comparison was made with the EOP results obtained by the IERS; this provided a first order validation. Table 1 contains the EOPs for the whole session and for the four stations only, as well as the IERS EOP values. The IERS values should be taken as reference values for this comparison. Comparing the EOP values obtained from the four stations against the 11 stations reveals a small difference, although there are larger differences between

the IERS and the four station or 11 station values. The largest difference is between the 11 station network and the IERS Ypol that showed a difference of 3.004 mas. The dut1 for all possible differences is less than 0.85 milliseconds. A special session to test this network might show an improvement of these values as scheduling will optimize source acquisition.

Table 1 The EOP results for the four-station strategic network and the complete network, as well as the IERS EOP values obtained for that session. The second row contains the estimated dut1 with errors, the third and fourth rows provide the Xpol and Ypol values with errors, and the fifth and sixth rows the dx and dy with errors.

EOPs	Strategic network	Complete network	IERS
dut1 (ms)	-306.00 ± 0.04	-306.057 ± 0.004	-305.207 ± 0.001
Xpol (mas)	-122.16 ± 0.62	-121.26 ± 0.1	-120.82 ± 0.06
Ypol (mas)	343.69 ± 0.28	344.15 ± 0.16	341.14 ± 0.06
dx (mas)	0.1 ± 0.15	0.14 ± 0.04	0.15 ± 0.04
dy (mas)	-0.09 ± 0.15	0.02 ± 0.03	0.06 ± 0.03

5 Conclusions

We demonstrated that fairly accurate EOP values can be obtained with a small network with appropriately long baselines. The fact that the TIGOCONC radio telescope is being moved to La Plata (Argentina) (i.e. changing the East - West baseline length) might change the values. The existing (small and not VGOS-compatible) TIGOCONC should be replaced by a modern fast-slewing VGOS antenna similar to the new antennas at Wettzell, instead of relying on the old antenna. This will greatly facilitate the generation of accurate and reliable EOPs using the proposed EU EOP network.

Acknowledgements

The authors acknowledge the International VLBI Service for Geodesy and Astrometry (IVS) and all its components for providing VLBI data. We are grateful to the National Research Foundation (NRF), South Africa, for supporting this project.

References

1. Böhm, J., Böhm, S., Nilsson, T., Pany, A., Plank, L., Spicakova, H., Teke, K. and Schuh, H. (2012) The new Vienna VLBI Software VieVS. *IAG Symposium 2009*, 136. Ed. Kenyon S., M.C. Pacino and U. Marti, 1007–1012.
2. Clark, B. G. (2003) In Radio Astronomy at the Fringe. *Astronomical Society of the Pacific Conference Series, ed. J. A. Zensus, M. H. Cohen & E. Ros*, Vol. 300, 1-58381.
3. Hale, B. (2007) Astronomy Methods. *Cambridge University Press*, p. 66. ISBN 978 0 521 53551 9.
4. International VLBI Service for Geodesy and Astrometry Network Stations `http://ivscc.gsfc.nasa.gov/stations/ns-map.html`
5. Lambeck, K.(1988) Geophysical Geodesy: The Slow Deformation of the Earth. *Oxford University Press*.
6. Schuh, H.(2000) Geodetic Analysis Overview, *In: IVS 2000 General Meeting Proceedings, Nancy R. Vandenberg and Karen D. Baver, editors*, p. 219-229.
7. Schuh, H and Böhm, J. (2013) Very Long Baseline Interferometry for Geodesy and Astrometry, in Guochang Xu (ed.): Sciences of Geodesy II, Innovations and Future Developments, Springer Verlag, ISBN 978-3-642-27999-7, doi: 10.1007/978- 3-642-28000-9, pp. 339-376.
8. Sovers, O. J., Fanselow, J. L. and Jacobs, C. S.(1998) Astrometry and geodesy with radio interferometry: experiments, models, results. *Reviews of Modern Physics*,70, 1393.
9. Thompson, A. R., Moran, J. M. and Swenson, G. W. (2007) Interferometry and Synthesis in Radio Astronomy. *John Wiley & Sons*.
10. Walker, R.C. (1999) Synthesis Imaging in Radio Astronomy II. *Astronomical Society of the Pacific Conference Series, ed. G. B. Taylor, C. L. Carilli & R. A. Perley*, Vol. 180, 433.