GSFC VLBI Analysis Center Report

David Gordon [1], Karen Baver [1], Sergei Bolotin [1], John Gipson [1], Karine Le Bail [1], Dan MacMillan [1], Leonid Petrov [2]

Abstract This report presents a description of the GSFC VLBI Analysis Center and its activities during 2017 and 2018. The GSFC VLBI Analysis Center analyzes all IVS sessions, makes regular IVS submissions of data and analysis products, and performs research and software development aimed at improving the VLBI technique.

1 Introduction

The GSFC VLBI Analysis Center is located at NASA's Goddard Space Flight Center in Greenbelt, Maryland. It is part of a larger VLBI group which also includes the IVS Coordinating Center, the CORE Operation Center, a Technology Development Center, and a VGOS station. The Analysis Center participates in all phases of geodetic and astrometric VLBI analysis, software development, and research. We provide several services and maintain several important data and information files for IVS and the larger geodetic community. These services include an atmospheric pressure loading service, a hydrology loading service, a nontidal ocean loading service, a ray tracing service, and an ECMWF meteorological data service. Data and information files include VMF1/VMF3 TRP files for every IVS session, the IVS Source Name Translation Table, various station information files, a file of source and station apriori's, a mean gradients file, a JPL planetary ephemeris file for *Calc/Solve/νSolve*, and several other files.

1. NVI, Inc./NASA Goddard Space Flight Center
2. NASA Goddard Space Flight Center

2 Staff

The Analysis Center staff consists of one GSFC civil servant and six NVI Inc. employees who work under contract to GSFC. Dr. Chopo Ma, a civil servant since the late 1970s, retired in September 2017. Dr. Leonid Petrov joined the group in September 2018 as a civil servant and the VLBI Lead Scientist. Dr. John Gipson is the GSFC VLBI Project Manager for NVI as well as the IVS Analysis Coordinator and an IVS Directing Board member. Other NVI analysis personnel include Dr. Daniel MacMillan, Dr. David Gordon, Dr. Karine Le Bail, Dr. Sergei Bolotin, and Ms. Karen Baver.

3 Analysis Activities

The GSFC VLBI Analysis Center analyzes all IVS sessions using the *Calc/Solve/νSolve* system, and performs the *fourfit* fringing and *Calc/Solve/νSolve* analysis of the VLBA-correlated RDV and other VLBA sessions. The group submitted analyzed databases to IVS for all R1, RV, R&D, AUST, AUG, AOV, AUA, APSG, CRF, CRDS, C17, V17, INT01, and INT03 sessions. During 2017/2018, GSFC analyzed approximately 375 24-hour IVS sessions and approximately 745 one-hour UT1 sessions (INT01, INT02, and INT03). Updated EOP and daily Sinex files were submitted to IVS immediately following analysis.

During 2018, the GSFC group led the transition from the old Mark3 database file system to the new vgosDB format within IVS. Currently all IVS correlators use the new format for database submission, and most other IVS Analysis Centers have now also switched to the vgosDB format.

4 Research Activities

- Third Realization of the International Celestial Reference Frame (ICRF3): Two NVI personnel (D. Gordon and S. Bolotin) actively participated in the generation of ICRF3 as members of the IAU ICRF3 Working Group. D. Gordon managed the data set used by the working group and generated two of the three ICRF3 catalogs. These included the X/S band catalog with 4,536 sources and the K-band catalog with 824 sources. This work included scheduling and processing of 22 VLBA astrometry sessions which were used to significantly improve ICRF3.
- Galactic Aberration: D. MacMillan, as chair of the IVS Galactic Aberration Working Group, investigated the estimation of the solar acceleration vector by many global solutions. He wrote a final report of the Working Group for IVS and made a presentation summarizing this report at the 2018 IVS General Meeting. He and the Working Group also wrote a paper on their results and will submit it to Astronomy and Astrophysics in early 2019. Using the ICRF3 data set, a galactocentric acceleration constant of 5.8 μas/yr in the direction of the galactic center was estimated and this value was adopted by the ICRF3 Working Group. This acceleration vector was within 8° (less than a 2-sigma deviation) of the direction of the galactic center.
- Gravitational Deformation: J. Gipson studied the effect of gravitationally induced deformation of VLBI antennas. Searching the literature he found models for Effelsberg, Gilcreek, Noto, Medicina, Onsala60, and Yebes40m, with the change in path lengths ranging from 2.5 mm (Gilcreek) to 100 mm (Effelsberg). He modified *Solve* to include the effects of these gravitational deformation models. *Solve* uses a table of the change in delays as a function of elevation angle, and uses spline-fitting to calculate delays at intermediate values. The dominant effect is a change in the estimate of the local Up component.
- High Frequency EOP: J. Gipson is chairing an IERS Working Group on HF-EOP. The goals of this Working Group are to recommend a replacement for the current IERS model, which is ∼20 years old. The new model will be used for ITRF2020. He gathered ten different HF-EOP models and put them in a common format. He also wrote software to calculate the predicted HF-EOP. As of the end of 2018, tests done using VLBI and GPS data indicate that the two best models are one based on TPX 8 altimetry data by Desai & Sibois, and an empirical model based on VLBI data by Gipson. The Working Group expects to make a final recommendation by June 30, 2019.
- EOP and TRF Scale from CONT Campaigns: D. MacMillan investigated the precision of EOP and scale from the CONT campaigns and found that these precisions have improved by more than a factor of two since 2002. CONT precision is significantly better than the R1 and R4 sessions, most likely because the same network is used continuously for all 15 days of each CONT campaign. Simulations showed that the expected precision with future VGOS networks should improve by a factor of 2–3 relative to current CONT precision. A paper discussing this investigation was published in the Journal of Geodesy in 2017.
- Source Declination Bias: D. MacMillan worked with L. McCallum (Univ. Tasmania) to develop an approximate model to correct for possible azimuthal errors at the KATH12M and HOBART12 antennas, based on the azimuthal dependence of phasecal group delays. The model removed about 75% of the declination bias observed between source positions estimated with data through 2017 versus ICRF2 source positions. The bias reached a maximum of about 90 μas at a declination of about $-20°$ to $-30°$ However, this correction was not used for ICRF3, because it increased the difference between the VLBI and Gaia positions, and it was believed that ICRF2 actually had a bias produced by galactic aberration.
- Geodyn VLBI Solution: D. MacMillan worked with F. Lemoine (GSFC) and D. Pavlis (U. Maryland) to validate VLBI processing with the new version of *Geodyn* by analyzing the 15-day CONT14 campaign. They found reasonably close agreement between EOP, wet zenith delays, and station position estimates from *Calc/Solve* versus *Geodyn* solutions. But there were some biases between some of the station position time series, which will require some further investigation.
- VGOS CONT17 Campaign: The GSFC group analyzed the VGOS CONT17 broadband sessions. Their analysis revealed the effects of source structure in the group delay residuals. To take this ef-

fect into account, S. Bolotin developed a multi-point source structure model and implemented it in *vSolve*.

- Source Work: We continued to monitor the proposed 195 Gaia transfer sources and observed the 30 weakest in R&D sessions. K. Le Bail selected sources for the CONT17 Legacy-1 network based on minimum fluxes, success rates, and structure indices. Lastly, the IVS Source Name Translation Table was maintained and updated numerous times, with a flag being added to indicate the source of the J2000 names.
- Source Noise Study: K. Le Bail collaborated with the Bordeaux Observatory and the Paris Observatory on using the Allan variance to study source time series. She also used the Allan variance to determine if different observation networks impacted the determination of source stability. And she developed a tool to compute the noise floor of source position time series using the Allan variance.
- INT01 Scheduling Improvement: K. Baver, with others, investigated INT01 scheduling improvement. She finished testing of the "BA 50" strategy of using 50 sources chosen to balance source strength and sky coverage (with J. Gipson), used new *Sked* algorithms to re-distribute the sources chosen for observing (with Gipson), evaluated the effect of source flux catalog latency (with Gipson and D. MacMillan), investigated improving the scheduling of Svetloe Intensives (with D. Behrend), and investigated mitigation of observing with a warm receiver (with E. Himwich). Baver also supported the start of the NEOS Operation Center's use of the BA 50 strategy.
- NVI, Inc. hosted four summer interns from Chalmers University during 2017 and 2018. In 2017, Johanna Renman and Sara Hällgren took different approaches to modeling the residual nutation estimates using techniques such as sliding least-squares, Kalman filtering, and ARIMA. Their goal was to see if we could come up with an a priori model of nutation for use in Intensive sessions. In 2018, Martin Henoch worked on Python codes to calculate atmospheric pressure loading using data from a coupled ocean-atmosphere model developed at GFZ to account for ocean bottom pressure changes due to the atmosphere. Also in 2018, Tilda Sikström worked on gathering gravitational deformation models from the literature. She found that these models could be well approximated by cubic splines and this has since been incorporated into the latest version of *Solve*.

5 Software Development

The GSFC VLBI Analysis Center develops and maintains the *Calc/Solve* analysis system, a package of ∼120 programs and 1.2 million lines of code. Several new versions were released in 2017 and 2018. An important new feature of *Solve* is the ability to estimate a galactic aberration constant.

S. Bolotin continued development of *vSolve* and the *vgosDB* software and utilities. *vSolve* is now fully operational and replaces the legacy interactive *Solve* program. These utilities as well as *vSolve* are distributed in one package, called "nusolve" and are available at https://sourceforge.net/projects/nusolve.

6 Publications

C. Gattano, S. Lambert, K. Le Bail, 'Extragalactic radio source stability and VLBI celestial reference frame: insights from the Allan standard deviation', in Astronomy & Astrophysics, 2018, vol 618, article A80, doi: 10.1051/0004-6361/201833430. (https://doi.org/10.1051/0004-6361/201833430)

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K. Le Bail, D. Gordon, J. M. Gipson, D. S. Macmillan, 'Investigating the noise floor of VLBI source positions', in Proceedings of the 23rd European VLBI Group for Geodesy and Astrometry, 2017, p. 186-189.

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L. McCallum, D. Mayer, K. Le Bail, M. Schartner, J. McCallum, J. Lovell, O. Titov, F. Shu, S. Gulyaev, 'Star Scheduling Mode—A New Observing Strategy for Monitoring Weak Southern Radio Sources with the AuScope VLBI Array', in Publications of the Astronomical Society of Australia, 34, 2017. doi:10.1017/pasa.2017.58.