

U.S. Naval Observatory VLBI Analysis Center

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Abstract This report summarizes the activities of the VLBI Analysis Center at the United States Naval Observatory for calendar years 2023–2024. During this period, Analysis Center personnel analyzed and made timely submissions to IVS of all R4, RV, CRF, and CRD databases; generated five biannual TRF/EOP/CRF updates; made available the USNO-INT-P series sessions; scheduled and analyzed VLBA astrometry sessions for ICRF maintenance and enhancement; studied the time variability of ICRF source positions; and engaged in research on active galactic nuclei (AGN).

based (EOP-S) Earth Orientation Parameters based on USNO VLBI global solutions. In addition to operational VLBI analysis, Analysis Center personnel are actively engaged in improving the precision and accuracy of UT1–UTC measurements from IVS and USNO/VLBA Intensives and in research related to future updates of the celestial and terrestrial reference frames. The RORFD also actively performs astrophysical research of active galactic nuclei (AGN) at radio, optical, and X-ray wavelengths. The RORFD also hosts the USNO Analysis Center for Source Structure—see its biennial report in this volume also.

1 Introduction

The USNO VLBI Analysis Center is supported and operated by the United States Naval Observatory (USNO) in Washington, D.C. It is part of the Radio Optical Reference Frame Division (RORFD) in the Celestial Reference Frame (CRF) Department at USNO. The primary services provided by the Analysis Center are the analysis of 24-hour diurnal VLBI sessions and UT1–UTC VLBI Intensive sessions, and the production of VLBI global solutions for estimation of the Terrestrial Reference Frame (TRF), the Celestial Reference Frame (CRF), and Earth Orientation Parameters (EOPs). The Analysis Center continued the submission to the IVS of Intensive (EOP-I) and session-

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USNO VLBI Analysis Center

IVS 2023+2024 Biennial Report

2 Analysis Center Activities

2.1 IVS 24-hour Session Analysis

During 2023–2024, personnel at the USNO VLBI Analysis Center performed the timely analysis and submission to IVS of all R4 sessions along with EOP updates and analysis reports within 24 hours of database release from the correlators. The Analysis Center performed the analysis and submission of all IVS-CRF and IVS-CRF-DS sessions, and also scheduled, analyzed, and submitted to the IVS all IVS-RDV VLBA sessions. Analysis personnel also analyzed all IVS-R1, IVS-T2, IVS-OHIG, and other diurnal IVS sessions, and submitted EOPs and analysis reports to IVS.

2.2 IVS Intensive Session Analysis and Support

Analysis personnel analyzed all IVS-INT-1, IVS-INT-2, IVS-INT-3, and IVS-INT-00 Intensive sessions and submitted timely UT1 measurements to IVS and to the USNO EOP Combination and Prediction Division (EOPCP). In 2024, the Analysis Center began analyzing the VGOS-INT-B and VGOS-INT-C VGOS Intensive sessions, which run for one hour on the ISHIOKA-ONSA13NE-ONSA13SW baselines. This VGOS network has occasionally been used as a substitute for the IVS-INT-1 X/S sessions, so this is an important activity to maintain.

The Analysis Center actively supported the INT-1 and INT-2 sessions during the period by providing time on the MK-VLBA antenna under the USNO's VLBA time share allocation. MK-VLBA time was provided every Saturday and Sunday to observe the INT-2 sessions for one hour, along with WETTZELL. MK-VLBA also observed the INT-1 sessions with WETTZELL on all American holidays, except Christmas. In June 2024, wildfires near the KOKEE station severely damaged the fiber optic line used for e-transfers, requiring KOKEE to ship their data on small disks to the Washington Correlator and other correlators, typically taking two to three days to arrive. Therefore, to ensure a low-latency UT1 measurement, the USNO Time Allocation Committee (TAC) made the MK-VLBA antenna available to observe the INT-1 sessions with WETTZELL and KOKEE every Monday, Tuesday and Thursday since June 2024. This allows a same-day UT1 analysis of the MK-VLBA to WETTZELL baseline. This support is expected to continue well into 2025 until the fiber is repaired and some upgrades are made to the KOKEE 20-meter antenna.

2.3 VLBA Intensive Sessions

The Analysis Center uses the Very Long Baseline Array (VLBA), operated by the National Radio Astronomy Observatory (NRAO), to provide a low-latency measurement of UT1–UTC through VLBA-only Intensive sessions. These originally used the 4796 km baseline from the MK-VLBA (Maunakea, Hawai'i) to

the Pietown (New Mexico) VLBA stations starting in 2011. In May 2020, we began observing these Intensives on the 7503 km baseline between the HN-VLBA (Hancock, New Hampshire) and MK-VLBA stations. These sessions are scheduled at the VLBA using the VieSched++ scheduling program and are run approximately every other day for a 90 minute period. Their precision is similar to that of the IVS-INT-1 sessions. In the spring of 2024, these sessions were added to the IVS master files for 2023 and 2024 as the USNO-INT-P series. The USNO Analysis Center uploaded the auxiliary files and analyzed vgosDBs associated with these sessions, and the Analysis Center now analyzes them with the same timeliness as the IVS-INT-1 sessions. Auxiliary files associated with these sessions that cannot be uploaded to the IVS data centers are available at the NRAO public website <https://www.vlba.nrao.edu/astro/VOBS/IVS>. In 2024, a method to rescale the estimated errors of the USNO-INT-P series was developed, and the UT1–UTC estimates with modified formal errors are now being used by the IERS Rapid Service / Prediction Center.

2.4 VGOS Session Analysis

Several X/S plus VGOS global solutions were made in order to locate the new VGOS stations in the VLBI TRF. The inclusion of many of the VGOS stations (in mixed mode) in R1 and R4 sessions has allowed for much better connections between the X/S TRF and the VGOS TRF. This made it practical to include VGOS sessions in our CRF/TRF/EOP solutions, which has been done for our latest biannual update, usn2024b, made at the end of 2024.

2.5 Conversion of Master Files and Renaming vgosDBs

In late 2022 the IVS Coordinating Center released the v2.0 master file format. Then, starting with 2023, vgosDBs were released in a new naming convention. To facilitate using a set of master files with the same format and vgosDBs with a consistent naming convention with the global solutions and regular analysis, the USNO Analysis Center converted all of its master files to the

new format and vgosDBs to the new naming convention in early 2024.

2.6 Biannual EOP/TRF/CRF Solutions

The Analysis Center generated three EOP/TRF/CRF solutions (usn2023a, usn2023b, and usn2023c) during 2023 and two during 2024 (usn2024a and usn2024b). These solutions, previously called ‘quarterly’ solutions, are now being run approximately every six months and include diurnal EOP series (Xpole, Ypole, UT1, dX, and dY) from 24-hour sessions, UT1 series (UT1–UTC) from Intensive sessions, and SINEX solution files for both diurnal and Intensive sessions. VGOS 24-hour sessions and selected VGOS Intensive sessions were also included in the latest solution, usn2024b, which can be found at <https://crf.usno.navy.mil/quarterly-vlbi-solution>.

2.7 VLBA Celestial Reference Frame Sessions

The Analysis Center scheduled, observed, processed, and analyzed monthly X/S astrometry sessions on the VLBA for the purpose of ICRF3 maintenance and expansion, for imaging of ICRF sources, and to improve and expand the upcoming fourth realization of the International Celestial Reference Frame (ICRF4) in 2027. Approximately 3000 sources were re-observed to improve their ICRF positions, and approximately 200 additional sources were added to the X/S CRF catalog during 2023 – 2024. At K-band (24 GHz), Analysis Center personnel also processed and analyzed monthly VLBA sessions plus several HARTRAO-YEBES40M and Korean VLBI Network (KVN) sessions. During the period, approximately 1200 K-band sources were observed multiple times to improve their positions, and approximately 260 new sources were added to the K-band CRF catalog for the future ICRF4. This K-band work also included observations of Sagittarius A*, the radio source associated with the supermassive black hole at the center of our galaxy, and we published a paper in the *Astronomical Journal* giving its precise position and proper motion in the ICRF3 frame.

2.8 Source Position Time Series Analysis

Analysis Center personnel generated several source position time series solutions at both X/S and K-band during the period. These solutions give the position of each source for each epoch for which it was observed. These solutions are being used to study the positional stability of ICRF sources. Comparisons were made of source stabilities at X/S vs. K band, which showed only a slight improvement in source stability at K-band. The latest time series solutions can be found at our web site at <https://crf.usno.navy.mil/quarterly-vlbi-solution>.

2.9 NURF

USNO and NRAO have undertaken a joint project called the NRAO/USNO Reference and Flux density (NURF) survey, to monitor important calibration sources with the VLBA, which will aid in future scientific and operational efforts, and will benefit the entire radio astronomy community. This project fits in well with normal VLBA observations, utilizing stations that would otherwise be idle such as during USNO-INT-P Intensive sessions. Currently, NURF observations are optimized as short snapshots to monitor flux density variability and to determine suitability as reference targets in the K-band. A reliable list of known and monitored phase reference targets across the sky is much needed in this band, as existing astronomical radio observatories further prioritize higher-frequency observations, and especially for efforts to support future observatories such as the ngVLA.

The current list of NURF sources primarily includes those that may be suitable for phase referencing, potential flux calibrators, and various important targets in the ICRF with the ability to add new sources as needed. Current observations are dynamically scheduled in astronomical imaging mode to obtain single scans with all available stations in both X/S- and K-band frequencies within a session to provide near-simultaneous multi-band information, and additional bands may be added in the future. All NURF data are in the process of being reduced in an automated workflow using the same CASA pipeline and python source extraction method developed at USNO for FRIDA data (see the USNO Analysis Center for Source Structure report for a description of FRIDA) and will be hosted

publicly on the USNO FRIDA web server. We expect processed NURF data to be available sometime in 2025.

2.10 Calc/Solve Replacement

Analysis Center personnel are collaborating with other USNO staff in writing replacement software for the Calc/Solve programs, which are currently being used for database analysis and global solutions. The Calc/Solve programs were developed and maintained by the Goddard Space Flight Center VLBI group. They are mostly written in Fortran, and this rewrite into more modern languages will help ensure flexibility and security in continued operations.

2.11 Participation in Domestic and International Meetings

RORFD personnel attended many domestic and international meetings to represent USNO and make various oral and poster presentations. Meetings attended included the 26th EVGA Working Meeting (Bad Kötzing, Germany), a K-band Workshop (Yebes Observatory, Spain), GGOS Days 2023 (Alcalá de Henares, Spain), the Thirteenth IVS General Meeting (Tsukuba, Japan), and the IAU XXXII General Assembly (Cape Town, South Africa).

3 Staff

Eight members of the RORFD participated in activities of the USNO VLBI Analysis Center during 2023–2024. They are listed below with their main Analysis Center activities.

- David Gordon (IVS-RDV, VLBA X/S- and K-band processing/analysis, ICRF solutions, VLBA time allocation).
- Christopher Dieck (Intensive analysis, USNO-INT-P PI, Intensive improvement research, internal software development and support).
- Phil Cigan (biannual global solutions, diurnal session analysis, P-series error inflation, NURF).

- Remington Sexton (diurnal session analysis, K-band processing/analysis, biannual global solutions, internal software development and support).
- Andrew Sargent (systems administration, Intensive and diurnal session analysis, AGN research).
- Christopher DiLullo (VLBA schedule management).
- Nathan Secrest (AGN research, P-series error inflation, RORFD supervision).
- Megan Johnson (formerly RORFD supervision, now at the National Science Foundation since June 2024).

4 Future Activities

The following activities are planned for 2025–2026 and beyond:

- Participate in ITRF2020 annual updates.
- Begin automated Intensive analysis.
- Generate two biannual TRF/CRF/EOP updates per year.
- Develop a new VLBI analysis software package.
- Continue maintenance and expansion of the ICRF-X/S and ICRF-K catalogs and participate in the next realization of the ICRF at multiple radio and optical wavelengths.
- Continue investigation of methods to report realistic formal errors in UT1 and other VLBI products.
- Continue AGN research.

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6 Publications

1. Cigan, Phil; Makarov, Valeri V.; Secrest, Nathan J.; Gordon, David; Johnson, Megan C.; Lambert, Sébastien: “Metrics of Astrometric Variability in the International Celestial Reference Frame: I. Statistical analysis and selection of the most variable sources”, *The Astrophysical Journal Supplement Series*, 274:28, October 2024. <https://doi.org/10.3847/1538-4365/ad6772>
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3. Dieck, Christopher; Secrest, Nathan; Cigan, Phil: “Adjusting Intensive Formal Errors”, *IVS 2024 General Meeting Proceedings*, pp. 176–180, edited by Dirk Behrend, Karen D. Baver, and Kyla L. Armstrong, NASA/CP-20250002586, 2025.
4. Dieck, Christopher; Behrend, Dirk; Bérubé, Mario; Haftings, Phillip; Thomas, Cynthia: “Mapping Session Codes to Session Types for the v2.0 Master File Format”, *IVS 2024 General Meeting Proceedings*, pp. 75–79, edited by Dirk Behrend, Karen D. Baver, and Kyla L. Armstrong, NASA/CP-20250002586, 2025.
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6. Gordon, David and Cigan, Phillip: “X/S versus K Band Source Stabilities from Time Series Analysis”, *IVS 2024 General Meeting Proceedings*, pp. 245–248, edited by Dirk Behrend, Karen D. Baver, and Kyla L. Armstrong, NASA/CP-20250002586, 2025.
7. Gordon, David; de Witt, Alet; Jacobs, Christopher S.: “Progress Towards ICRF4 at X/S and K Bands”, *IVS 2024 General Meeting Proceedings*, pp. 264 – 267, edited by Dirk Behrend, Karen D. Baver, and Kyla L. Armstrong, NASA/CP-20250002586, 2025.
8. Johnson, Megan C.; de Witt, Aletha; Jacobs, Christopher; Gordon, David; Cigan, Phillip J.; Sexton, Remington O.: “K-Band 24-hour EOPs and UT1–UTC Intensives”, *IVS 2024 General Meeting Proceedings*, pp. 249–253, edited by Dirk Behrend, Karen D. Baver, and Kyla L. Armstrong, NASA/CP-20250002586, 2025.
9. Makarov, Valeri V.; Cigan, Phil; Gordon, David; Johnson, Megan C.; DiLullo, Christopher; Lambert, Sébastien: “Partial Alignment of Astrometric Position Excursions of International Celestial Reference Frame Quasars with Radio Jet Structures”, *Astrophysical Journal Letters*, volume 977, 14, 2024. <https://doi.org/10.3847/2041-8213/ad94f1>