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Updating JPL's VLBI Processing Pipeline for ITRF2020–u2023 Compliance and IVS Standards

Alexander Tolstov[*,§], Konstantin Belov[*], Christopher Jacobs[*], Gabor Lanyi[*], and Charles Naudet[*]

ABSTRACT. — This report outlines ongoing efforts to update the Jet Propulsion Laboratory's (JPL) MODel and ESTimate (MODEST) software [1] to comply with International Earth Rotation and Reference Systems Service (IERS) conventions [2] and the International Terrestrial Reference Frame (ITRF) [3], while also advancing the framework's automation and analytical capabilities. Current development priorities include adding the modeling of galactic aberration drift [4], pole tide loading [5], and atmospheric effects [6], along with additional enhancements to JPL's processing workflow. A new Python-based pipeline automates the transformation of vgosDB [7] sessions into analysis-ready inputs[1], incorporating robust pre-screening, flexible model configuration, and iterative outlier rejection, with automation extended to the preparation and packaging of Software INdependent EXchange (SINEX) [8] deliverables for operational use. The resulting SINEX-compliant outputs—comprising Earth orientation parameters (EOP) and station coordinates—contribute directly to JPL's role in the global geodetic infrastructure and Very Long Baseline Interferometry (VLBI) reference frame realization. A recent solution using data from 2010 to 2022 yielded UT1-UTC residuals with a weighted root mean square (WRMS) of 13.4 microseconds (µs), demonstrating that these improvements have preserved MODEST's accuracy, comparable to other state-of-the-art VLBI solutions, while substantially reducing the need for manual session editing and user intervention.

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[*]Deep Space Tracking Systems Section

[§]Arizona State University

[1]O. J. Sovers, "MODEST User Manual," Jet Propulsion Laboratory, California Institute of Technology, Internal Memo, Jan. 2009, unpublished internal document.

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I. Introduction

Very Long Baseline Interferometry (VLBI) is a fundamental technique in geodesy and astrometry used to measure Earth's rotation, to measure plate tectonic motion, and to maintain the celestial and terrestrial reference frames [9]. As a participating analysis center within the International VLBI Service for Geodesy and Astrometry (IVS), the Jet Propulsion Laboratory (JPL) is in the process of updating its VLBI analysis framework to better align with standards established by the International Earth Rotation and Reference Systems Service (IERS) conventions [2] and the International Terrestrial Reference Frame (ITRF2020–u2023) [3].

Current development work emphasizes refinements to key geophysical models—including atmospheric mapping functions [10, 11], secular aberration corrections [4], and pole tide formulations—to enhance the precision of Earth orientation parameters (EOPs), source positions, and station coordinates [12]. These modeling efforts are guided by the IERS 2010 conventions [2], which define the standards for geodetic and astronomical modeling used in global reference frame realization.

The following sections outline the structure and methodology of these ongoing updates, which center around MOdel and ESTimate (MODEST) [1], JPL's primary VLBI processing software. MODEST employs least-squares estimation to model VLBI observables and estimate geodetic parameters. While the framework largely adheres to IERS 2010 conventions, targeted refinements are underway to enhance compliance and improve modeling precision [13]. Section II describes the automation of data acquisition; Section III outlines the processing pipeline that prepares VLBI sessions for estimation; Section IV evaluates MODEST's geophysical and relativistic model compliance with IERS 2010 conventions [2]; Section V evaluates the performance of the analysis framework by comparing UT1–UTC residuals against reference solutions and presenting source position residuals for the International Celestial Reference Frame (ICRF) source 4C 39.25 (ICRF J0927+3902), including a weighted RMS of 467 µas in declination.

Figure 1 provides an overview of the automated pipeline, beginning with session download and ending with parameter estimation via MODEST. The analysis pipeline is designed to allow flexible updates and the insertion of additional filters, revised models, and configurations.

II. Data Acquisition

The data set used in this study comes from the Crustal Dynamics Data Information System (CDDIS), an online repository of geodetic and geophysical data [14]. CDDIS maintains a comprehensive collection of VLBI observational data. This study specifically examines S/X dual-band VLBI sessions stored in the vgosDB format [7], which is the IVS standard for storing, transmitting, and archiving VLBI data. A

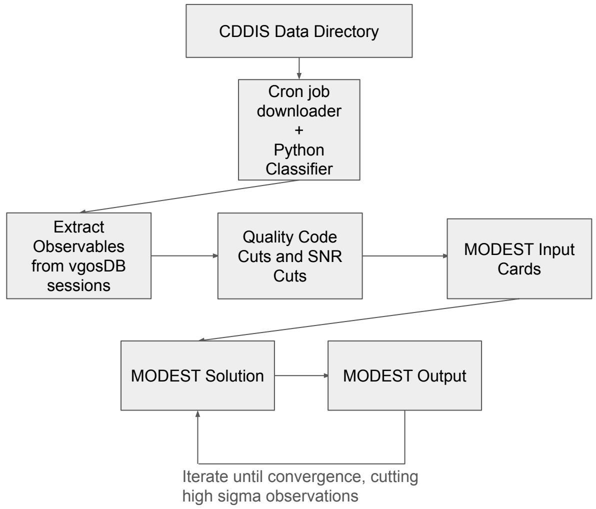

Figure 1. JPL VLBI Processing Pipeline

vgosDB is a session-level data container composed of NetCDF and ASCII files that provide nearly all information required to process a single VLBI session, including delay observables, metadata, and system diagnostics. Although this report focuses on S/X-band processing, the pipeline is designed to handle K-band data and is currently being extended to support X/K dual-band observations as part of ongoing updates.

The downloaded data set consists of a time series of VLBI sessions, typically ranging in duration from 4 to 24 hours, covering the period from 1998 to 2025. It includes multiple intercontinental baselines, which are essential for the derivation of high-precision EOPs and station coordinate estimates. These data are useful for refining terrestrial reference frame solutions and enhancing the accuracy of geophysical modeling.

Data acquisition is fully automated using background processes that run two Python scripts: One downloads VLBI session files directly from the CDDIS archive, and the other parses the IVS master schedule to classify sessions by type. The data used in our analysis consist primarily of 24-hour sessions, particularly IVS-R1 and IVS-R4 [15] observation sessions.

Before entering the main processing workflow, all VLBI session files undergo an initial pre-screening stage to ensure baseline data quality and integrity. Details of this stage, along with the full suite of applied filters, are described in Section III as part of the data processing pipeline.

III. Automated Processing Pipeline

The core of JPL's VLBI analysis framework is built around the MODEST [1] software package, a legacy least-squares estimation tool used to derive geodetic parameters from VLBI observations. This pipeline prepares MODEST-compatible input files, executes MODEST iteratively with outlier rejection between runs, and converts the final estimates into Solution INdependent EXchange (SINEX), a standardized format for exchanging geodetic solutions, compliant formats [8]. Together, these steps streamline the transformation of vgosDB sessions into robust geophysical outputs consistent with ITRF2020–2023 standards [3]. A full listing of MODEST's configurable models and options is provided in Appendix 4, and its compliance with IERS 2010 conventions is discussed in Section IV.

A. Input Data Organization

The VLBI observables from the vgosDB sessions are parsed into a hierarchical Python dictionary structure, with each entry indexed according to its chronological sequence within the session. Each observation entry contains nested attributes such as group delay, phase delay, uncertainties, signal-to-noise ratio (SNR) values, and quality code information. This structured approach enables efficient filtering, modification, and organization of data for seamless ingestion into MODEST.

Table 1. Illustration of internal pipeline Python dictionary data structure for VLBI observation data, showing key fields including group delay and SNR.

Obs.	Time (UTC)	Baseline	Source	...	Group Delay X (s)	SNR X	Quality Code X
0	2020-07-10 05:18	BADARY-KOKEE	1418+546	...	-6.55e-3	18.65	9
1	2020-07-10 05:18	BADARY-NYALES20	1418+546	...	-3.41e-3	19.30	9
2	2020-07-10 05:18	BADARY-SVETLOE	1418+546	...	2.69e-3	87.16	9
3	2020-07-10 05:18	BADARY-WETTZ13N	1418+546	...	6.22e-3	30.63	9
4	2020-07-10 05:18	BADARY-WETTZELL	1418+546	...	6.22e-3	41.11	9
5	2020-07-10 05:18	BADARY-YEBES40M	1418+546	...	8.34e-3	49.30	9
6	2020-07-10 05:18	KOKEE-NYALES20	1418+546	...	3.15e-3	12.76	9
7	2020-07-10 05:18	KOKEE-SVETLOE	1418+546	...	9.24e-3	26.67	9
				...			

Table 1 presents an example set of baseline-dependent group delay and SNR values. A typical vgosDB session includes many such sources, each contributing differently depending on its sky location and intrinsic structure. Variations in group delay, both in sign and magnitude, can arise from baseline geometry and source structure effects, such as asymmetric emissions or extended jet features. These structural asymmetries can shift the apparent centroid of emission, leading to baseline-dependent delay signatures. The data are organized into a nested Python dictionary, where each VLBI observation is indexed by station pair and timestamp. This format allows for efficient filtering, attribute access (e.g., delay, phase, SNR), and direct translation into MODEST-ready input.

B. Initial Quality Control and Observation Screening

Each vgosDB session is subjected to an initial pre-screening step that removes incomplete, invalid, or nonphysical observations prior to formal analysis. This stage is intended to ensure that only structurally sound and interpretable data proceed through the remainder of the pipeline.

Observations are excluded for a number of reasons. Entries with undefined or unphysical group delay or phase delay values are discarded immediately. In particular, any delay value equal to zero or with a formal error exceeding 1 second is flagged and removed, as such values are considered physically unrealistic in geodetic VLBI. Measurements containing unrealistic ionospheric delay values, unresolved subambiguity issues, or missing meteorological metadata—such as surface pressure or humidity—are also removed, unless reliable auxiliary data are available.

In addition to basic checks, the pipeline inspects observation-level data flags defined in the vgosDB. These include flags on group delays, ionospheric delays, phase delays, and other key observables. The flags are integer-coded, with standardized values assigned as follows: “0” indicates a valid observation, “-1” denotes missing data, “-2” indicates bad data, “-3” flags a sigma that is too small, and “-4” flags a sigma that is too large. These definitions help isolate corrupted, incomplete, or statistically unreliable observations across multiple data types. By default, pre-screening exclude observations with non-zero data flags.

To enforce quality consistency, the pipeline applies a filter based on the IVS-assigned quality code, which is an integer value from 0 to 9 used to characterize the reliability of each observation. These codes are assigned by the IVS service center analyzer based on metrics such as internal consistency, residuals, and solution stability. A code of 9 indicates the highest level of confidence, while lower values reflect various issues ranging from moderate inconsistency to complete unreliability [16]. Only observations with a quality code of 9 are retained in this analysis.

Following the quality code cut, a SNR threshold is applied to exclude observations that fall below a minimum acceptable value. This threshold is user-configurable and is set to 6.8 by default.

The pre-screening phase also incorporates user-defined exclusions, enabling specific stations or sources to be removed from analysis based on known issues or testing needs. These combined filters represent the first stage of quality control in the pipeline and are critical for ensuring the reliability and stability of the downstream MODEST solutions. A summary of the applied filters is provided in Table 2.

Table 2. Summary of pre-screening quality control filters applied to VLBI session data.

Filter Type	Description
Bad Phase Values	Removes unphysical or undefined phase-derived delays (e.g., zero values or formal errors exceeding 1 second)
Bad Delay Values	Filters out group delays outside expected physical ranges (e.g., zero values or formal errors exceeding 1 second)
Bad Data Flags	Excludes observations with invalid data flags
Bad Ionosphere Corrections	Removes observations with unrealistic ionospheric delay corrections (e.g., zero values or formal errors exceeding 1 second)
Quality Code Cuts	Discards observations with quality codes below a specified threshold (default: 9)
SNR Cuts	Excludes observations with SNRs below the cutoff (default: 6.8)
Subambiguity Cuts	Removes observations with unresolved subambiguity issues
Missing Meteorological Data	Filters observations from stations lacking pressure or humidity data unless a fallback source is provided
Station Excludes	Excludes observations from user-specified stations
Source Excludes	Excludes observations from user-specified sources

C. Metadata Completion and Fallback Handling

A priori parameters—such as station positions and velocities, and source positions and velocities—are incorporated into the pipeline to initialize the estimation process and constrain the solution. Station parameters are sourced either from the latest realizations of the ITRF or from the JPL Terrestrial Reference Frame (JTRF) [17], depending on the session and analysis context. Source positions are initialized in the desired celestial reference frame, typically ICRF3 [18]. EOPs, including UT1 predictions, are obtained from standard prediction files. Additional geophysical parameters, such as ocean loading corrections, are applied using pre-computed lookup tables.

Typical a priori accuracies expected for global geodetic VLBI processing are on the order of 1–10 cm for station positions, a few microseconds for station clock models, and a few milliarcseconds for EOPs. While the pipeline is robust to minor mismodeling, significantly degraded a priori values can hinder convergence or introduce spurious signals into the solution.

Despite these preparations, certain observational metadata are occasionally missing from the raw session files. Common omissions include cable calibration (Cable-Cal) delays, quality codes, SNR values, and local meteorological data. In the absence of Cable-Cal values, a zero-delay assumption is applied. Missing meteorological data, such as surface pressure or temperature, is supplemented using data from the Vienna Mapping Function 3 (VMF3) model [11].

Observations lacking quality codes or SNR values are typically excluded during the pre-screening phase to preserve data integrity. However, if all observations in a session are missing these fields, fallback values are assigned uniformly to salvage the session and allow it to proceed through the pipeline.

D. Iterative Estimation with MODEST

After the observation data are filtered and converted into MODEST-compatible input, the least-squares estimation process begins. At each step, MODEST computes the pre-fit residuals—the differences between the observed VLBI group delays and the delays predicted by the configured geophysical models. These pre-fit residuals represent the initial observed-minus-computed (O–C) discrepancies and are used to identify the largest outliers prior to solving.

Observations with exceptionally large pre-fit residuals are excluded before proceeding to parameter estimation. This ensures that extreme outliers, typically due to data corruption or modeling failures, do not bias the solution. The remaining data are then passed into MODEST's iterative least-squares estimator, which solves for session-specific parameters and produces post-fit residuals—the differences between observed delays and the model-predicted values after parameter adjustment.

Post-fit residuals are normalized by their expected formal uncertainties to compute normalized chi-squared statistics. These values are used to assess internal consistency and guide further data rejection. At each iteration, the solution is reevaluated, and additional observations are reweighted or removed if their post-fit residuals exceed configurable sigma thresholds. The process begins with lenient thresholds (to avoid excessive early rejection) and tightens them across iterations to refine the data set progressively.

As with most filtering parameters in the analysis framework, the sigma thresholds used during iteration are user-configurable. By default, the first two iterations remove observations with formal errors (sigmas) greater than or equal to 1000. This is followed by cuts at ≥ 100 sigma, ≥ 30 sigma, and finally ≥ 7 sigma. These thresholds are applied to the normalized residuals, which are computed as the difference between the measured and modeled delay divided by the observation's sigma. These sigmas represent the formal or reweighted uncertainty associated with each observation and form the statistical basis for identifying outliers. After each cut, the solution undergoes an estimation cycle in which parameters such as station positions, clocks, and EOPs are allowed to adjust. As a result, both the residuals and observation weights evolve across iterations, and the sigmas themselves may change due to reweighting. Removing large outliers early in the process helps the solution stabilize and reduces the chance of otherwise valid observations being rejected due to distortion from extreme residuals. Once the 7-sigma threshold is reached, it is no longer decreased, but observations exceeding it may still be rejected in later iterations as the solution continues to converge and the residuals are refined.

This iterative cycle continues until convergence is achieved—when the normalized chi-squared value stabilizes within 5% of unity, no further changes in weights or rejections occur, or a maximum of 20 iterations is reached. The iteration cap serves as a safeguard against non-convergent solutions, which may arise due to persistent data contamination, model misconfigurations, or inconsistencies in the input. Sessions that reach this limit are typically flagged for further inspection or excluded from downstream analysis. Figure 2 illustrates the evolution of normalized chi-squared statistics across iterations, demonstrating how the solution becomes increasingly stable and robust.

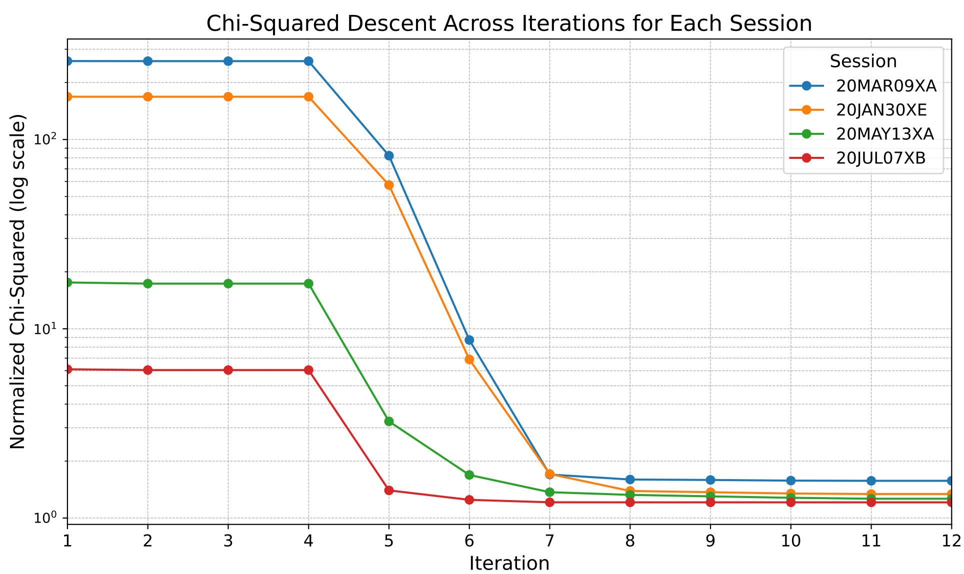

Figure 2. Convergence of normalized chi-squared values across iterations for selected single-session solutions. In well-behaved sessions, convergence is typically achieved within five to seven iterations. The filtering process begins with a series of increasingly strict sigma cuts—removing observations with formal errors $\geq$ 1000, $\geq$ 100, $\geq$ 30, and finally $\geq$ 7. After the 7-sigma threshold is applied, no further tightening occurs, but residual-based reweighting and rejection continue until convergence criteria are met.

Although the iterative process aims to drive the normalized chi-squared value toward unity, the final stabilized value often remains above 1 (e.g., around 1.5 in Figure 2). This indicates that the residual scatter exceeds the formal uncertainties assumed in the weighting model, likely due to unmodeled errors, imperfect stochastic assumptions, or residual inconsistencies in the observation set.

All sigma thresholds, weighting strategies, and iteration limits are fully configurable within the MODEST pipeline, allowing users to adapt the procedure for specialized experiments or validation scenarios.

IV. Conventions Compliance and Targeted Model Updates

MODEST's geophysical and relativistic modeling framework is broadly compliant with the IERS Conventions 2010 (Technical Note No. 36, hereafter TN36) [2]. It supports a wide range of configurable models for clock, troposphere, ionosphere, and other geophysical effects. A full list of available modeling options is provided in Appendix I.

MODEST implements the VMF1 [10], providing tropospheric mapping that fully conforms to TN36 recommendations, and applies octupole (degree-3) solid Earth tide modeling, which fully meets the specifications for tidal deformation modeling.

MODEST includes ocean tide loading based on FES2014 [19], which exceeds IERS 2010 requirements, and applies an internal JPL-developed model for pole tide corrections. However, this pole tide model is currently being updated to adopt the formulation of Desai (2002) [5] to ensure full compliance with TN36. The relativistic delay model conforms to the VLBI consensus formulation, and dual-frequency ionospheric corrections are applied to meet first-order dispersive delay requirements.

For precession and nutation of the Celestial Intermediate Pole (CIP), MODEST currently uses the IAU2000 [20] model along with the Yoder model for Free Core Nutation (FCN). To achieve full TN36 compliance, the precession model will be upgraded to IAU2006 [21], and the FCN model will be replaced with that of Lambert (2007) [22]. Atmospheric loading is modeled using an internal JPL solution, which will be replaced by the Ponte and Ray (2003) model [6]. Lastly, antenna thermal deformation is currently handled via an internal JPL-developed model, but to align with TN36, an upgrade to the model described by Nothnagel (2009) [23] is planned.

MODEST uses a JPL-developed gravitational well geopotential model. However, an update to EGM2008 [24] is planned to maintain compiance with TN36. In the relativistic delay module, MODEST employs a fully compliant formulation; however, the planetary ephemeris has been upgraded to JPL DE441 [25], which exceeds TN36's DE421 [26] requirement and ensures maximal accuracy for gravitational delay modeling. The celestial reference frame has also been upgraded to ICRF3 [18], providing improved alignment with the latest international standards. MODEST continues to output station positions in the ITRF1993 [27] frame, per requirements from JPL's navigation teams; however, a transition plan to adopt ITRF2020-u2023 is underway to ensure full compatibility with modern geodetic products.

Higher-order ionospheric corrections, such as second-order magnetic field effects, are not included in MODEST, which is consistent with TN36 expectations but remains a potential area for future enhancement.

Several targeted updates are planned to strengthen the MODEST framework. These include implementing the VMF3 [11] for enhanced tropospheric delay modeling under varied atmospheric conditions, incorporating galactic aberration corrections to address the long-term secular drift of extragalactic reference sources [4].

These enhancements aim to maintain MODEST's alignment with evolving IERS standards and support next-generation VLBI product accuracy. A full list of compliance and planned improvements is listed in Table 3.

Table 3. Summary of model compliance with IERS Conventions 2010 (TN36) and planned updates.

Model Component	TN36 Compliant	Notes
Troposphere Mapping (VMF1)	Yes	VMF1 is fully supported and TN36-compliant. Upgrade to VMF3 is planned for enhanced accuracy in variable atmospheric conditions.
Solid Earth Tides (Octupole)	Yes	Includes degree-3 terms; meets TN36 tidal deformation requirements.
Ocean Tide Loading	Yes+	Implemented using FES2014, which exceeds TN36 requirements.
Pole Tide Correction	No	Uses internal JPL model; update to Desai (2002) is in progress to ensure compliance.
Atmospheric Loading	No	Based on a JPL-developed model; update to Ray and Ponte (2003) is planned.
Antenna Thermal Expansion	No	Current model is JPL-internal; planned upgrade to Nothnagel (2009) for TN36 alignment.
FCN	No	Yoder model currently used; upgrade to Lambert (2009) is planned.
Planetary Ephemeris (DE441)	Yes+	DE441 exceeds TN36 requirement of DE421, offering higher accuracy for relativistic delay modeling.
Celestial Frame (ICRF3)	Yes+	Upgraded to ICRF3, improving alignment with modern VLBI standards.
Reference Frame Output (ITRF1993)	No	Legacy output for JPL navigation; transition to ITRF2020-u2023 underway.
Higher-Order Ionosphere	N/A	Not required by TN36; currently omitted but noted as potential future enhancement.

While some updates to geophysical models—such as pole tide corrections, atmospheric loading, and antenna thermal expansion—are still in progress, we do not expect their omission to significantly impact the overall accuracy of current VLBI-derived parameters. A summary of implemented models, pending updates, and areas for future improvement is provided in Table 4 to document the pipeline's current capabilities and planned enhancements.

V. Estimated EOPs and Station Coordinates

As part of the MODEST pipeline, many geodetic parameters are estimated, including EOPs such as UT1–UTC, and station positions. Figure 3 presents UT1–UTC estimates produced by MODEST in the ITRF2020–u2023 frame, compared against the JPL Space Series 2020 EOP. The WRMS of the residuals remains below 13.4 µs, which is consistent with the performance of other IVS analysis centers and aligns with expectations from the ITRF2020 combination by Altamimi et al. [28], where WRMS values of UT1–UTC residuals are typically below 15 µs. Simarily, the weighted RMS of the X-pole and Y-pole for MODEST yields values of 215 µas and 211 µas, respectively. This also agrees very closely with studies from the Viena VLBI center and the United States Naval Observatory (USNO) [29], whose results ranged from 228-130 µas and 405-218 µas for X-pole and Y-pole, respectively.

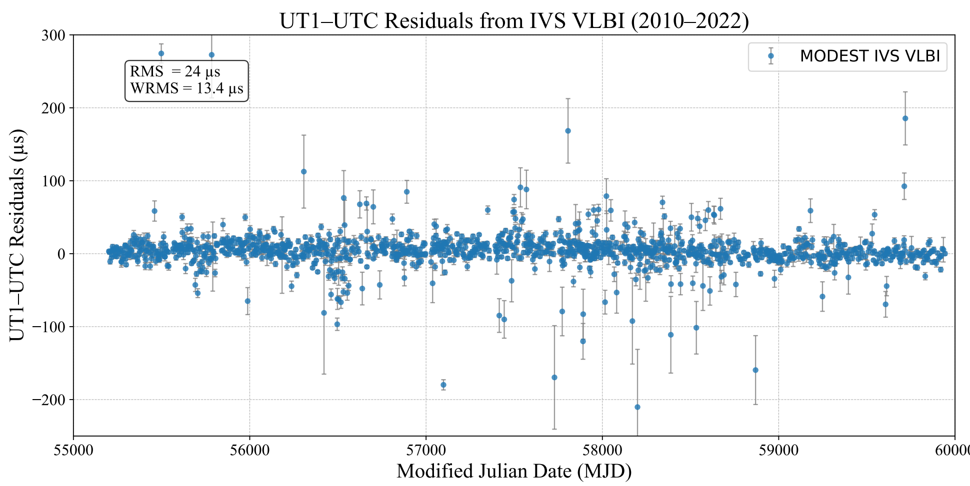

Figure 3. UT1—UTC residuals generated by MODEST.

To further validate the positional accuracy achieved by MODEST, we evaluated the declination estimates for the source 4C 39.25 (ICRF J0927+3902) relative to its ICRF3 catalog position. The analysis initially included all available VLBI sessions, but only those completing successfully—i.e., without processing failures—were retained. A constant bias of 2000 µas was subtracted from the residuals to account for a systematic offset. Observations with detrended residuals beyond ± 2000 µas and those flagged as 3-sigma outliers based on formal error were excluded. The resulting filtered dataset yields a WRMS of 467 µas, a value consistent with expectations for geodetic single-session VLBI solutions. These results confirm that MODEST can deliver catalog-quality astrometric positions even without full integration of IERS

TN36 model refinements. Figure 4 presents the time series of declination residuals for 4C 39.25.

The robustness of the current MODEST implementation is further supported by previous work showing that, with the addition of the European Space Agency's (ESA) Malargüe antenna and the adoption of 2048 Mbps Deep Space Network (DSN) operations in 2014, X/Ka-band VLBI achieved median positional precision comparable to ICRF2 for over 500 common sources [30]. When considered alongside the results, this builds confidence in MODEST's ability to deliver high-precision astrometric outputs, even in the absence of full IERS TN36 model compliance.

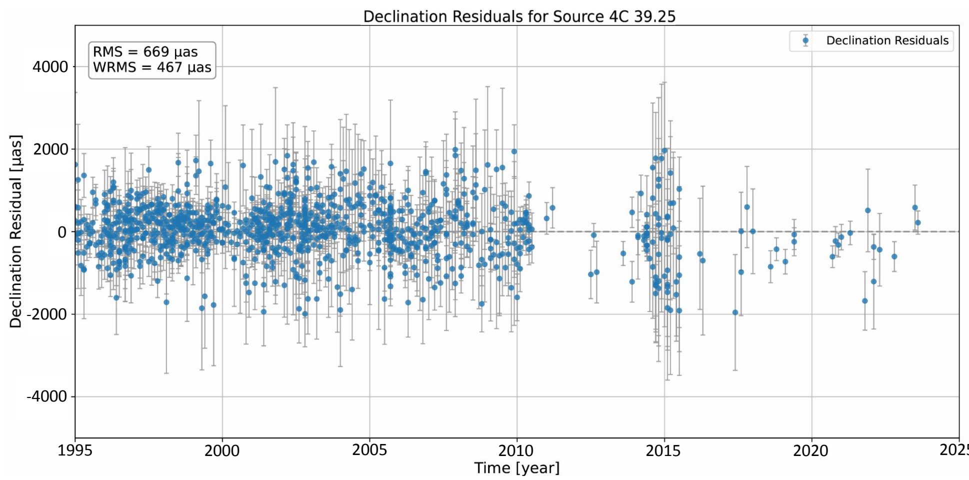

Figure 4. Declination residuals for source 4C 39.25 (ICRF J0927+3902) relative to ICRF3. The inset box summarizes the unweighted RMS and WRMS of the post-processed residuals, computed after removing large outliers and applying a best-fit linear trend. Each data point corresponds to a single-session solution. The resulting weighted RMS scatter of 467 µas demonstrates strong internal consistency and agreement with the catalog position.

VI. Conclusion

This work presents a modernized VLBI processing pipeline developed at JPL to support the ITRF2020–u2023 realization and align with current IVS standards. The pipeline automates session handling, pre-screening, and iterative estimation via the MODEST framework, enabling efficient large-scale analysis of geodetic VLBI data.

The resulting EOPs and station coordinates demonstrate high internal consistency and strong agreement with independent reference solutions. This performance is achieved even though several lower-level modeling components, such as atmospheric loading and FCN corrections, are still pending full updates.

While the pipeline incorporates IERS-compliant models and robust filtering strategies, several areas remain open for refinement. Cable-Cal delays are currently treated with a zero-delay assumption, and fallback metadata values are used only when all observations lack quality codes or SNRs. These practices, while conservative, may introduce minor biases in certain sessions.

Although the system currently outputs in the ITRF1993 frame to meet JPL navigation requirements, a transition to ITRF2020–u2023 is underway to enhance downstream compatibility.

Ongoing development focuses on implementing the VMF3 and integrating galactic aberration corrections. Although not yet fully TN36 compliant, MODEST is producing EOP, station locations, and ICRF catalog results that are competitive with other VLBI analysis sites. These planned enhancements will further ensure the pipeline remains robust, flexible, and aligned with next-generation geodetic VLBI requirements.

Acknowledgments

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APPENDIX

I. MODEST Model Specifications

To ensure compliance with ITRF2020–2023 modeling standards and IVS Working Group recommendations, the MODEST software supports a broad range of configurable geophysical and processing models. These control how observational data are filtered, modeled, and weighted during the least-squares estimation process. For traceability and reproducibility, Appendix I provides a comprehensive summary of all MODEST modeling options, categorized by function and showing available settings alongside their defaults. For most fields, options to select specific models are provided. If a model choice is presented as a "Yes" or "No" option, it indicates that an internally developed JPL model is being used.

Table 4. MODEST Model Specification Table.

Model	**Category**	**Use**	**Choices (default first)**
		GENERAL	
GENERAL	Input debug level	1	0, 1
	Partial precision	Double	Double, Single
	Print O-Cs	Yes	Yes, No
	Troposphere sigmas	Wet	No, Yes, Dry(=Yes), Wet
	Ionosphere sigmas	No	No, Yes
	SNR threshold	0,0/	1,1/
	PCAL applied	No	No, Yes
	All channels OK	No	No, Yes
	Linear combinations	No	No, Yes
	Write formatted file	No	No, Yes
	Write C_n file	No	No, Yes
	O-C debug level	1	0, 1
	Fit file format	ASCII	Binary, ASCII
		CLOCKS	
CLOCKS	Polynomial	L	Q(Quadratic), L(Linear)
	S/X clock offset	No	No, Yes
	Temperature clock	No	No, Yes
	Local UT correction	Yes	Yes, No
	Stochastic params.	No	No, Yes
	DR Delta time	0.1D0	0.1D0, 2.D0
	Debug level	0	0, 1, 2
		TROPOSPHERE	

Table 4. MODEST Model Specification Table (continued)

Model	Category	Use	Choices (default first)
TROPO-SPHERE	Mapping function	Niell	Lanyi, Davis, Chao, Herring, Niell, Chaotbl, Chaomod, LanyiC, Ifadis, VMF1
	Surface temperatures	Yes	No, Yes
	Pressure a prioris	Yes	No, Yes
	Wet partials	Yes	No, Yes
	Rate partials	Yes	No, Yes
	Map partials	No	No, Yes
	Azimuth dependence	No	No, Yes
	Trp. cov. parameters	No	No, Yes
	Trpcov convergence	1.0D-4	1.0D-4
	Debug level	1	0, 1, 2
	EARTH ORIENT		
EARTH ORIENT	Precession	IAU	IAU, Unity
	Precession partials	No	No, Yes
	Tweak partials	No	No, Yes
	Nutation	MHB2000	IAU, Herrng86, Woolard, Unity, Zhu1, Zhu2, ZMOA-2, KSNRE, KSV94-1, KSV94-4, KSV96-3, IERS96, MHB2000
	Nut. angle partials	No	No, Yes
	Nut. ampl. partials	No	No, 50(number)
	Nut. from UTPM file	No	No, Yes
	TDB time correction	Kaplan	Kaplan, Moyer
	Eqn. of equinoxes	IERS96	MFIT, IERS92, IERS96
	Slow UTPM correction	Yoder	Yes, No, Yoder, IERS92
	Fast UTPM correction	IERS2000	No, Yes, 1d, 30d, 180d, All, JPL92, HD94, Ray94, GSFC95, Herr95, Gpsn95, IERS2000
	Ocean UT lunar node	No	No, Yes
	UTPM rate partials	Yes	No, Yes
	UTPM tidal partials	No	No, Yes
	Debug level	0	0, 1, 2, 3
	IONOSPHERE		
IONOSPHERE	TEC partials	No	No, Yes
	Efron factor	No	No, Yes

Table 4. MODEST Model Specification Table (continued)

Model	Category	Use	Choices (default first)
	Debug level	0	0, 1, 2
		STATIONS	
STATIONS	Maximum number	15	15, (number)
	Coordinate system	Cart	Cyl(indrical), Cart(esian)
	Rate partials	No	No, Yes
	Gamma partials	No	No, Yes
	A priori gamma	1.0D0	1.0D0, (value)
	Plate motion model	A priori	None, AM0-2, AM1-2, NUVEL-1, NNR-NVL1, NUVEL-1A, NNR-NV1A, A priori
	Solid Earth tides	Octu	Quad, Octu, Yes, No
	Vertical Love #	0.609D0	0.609D0, (universal)
	Horizontal Love #	8.52D-2	8.52D-2, (universal)
	Tide phase	0.0D0	0.0D0, (degrees)
	Ocean loading	Yes	Yes, No, Luncor
	Ocean load partials	No	No, Yes
	Pole tide	Yes	Yes, No
	Tide freq. variation	JPL94-1	IERS92, JPL94-1, Mthws95, None
	Atmosphere loading	No	1,2, Yes
	Atm. load partials	No	No, Yes
	Ant. thermal exp.	Yes	No, Yes
	Ant. offset bending	No	Yes, No
	Antenna trop. corr.	No	No, Yes
	Polarization (phase)	RCP	None, RCP, LCP
	PPN scaling	TDT	TDT, EC, Coord, None
	Debug level	0	0, 1, 2
		SOURCES	
SOURCES	Maximum number	999	500, (number)
	RA, dec rates	No	No, Yes
	Structure correction	No	No, Yes
	Structure partials	No	No, Yes
	Parallax partials	No	No, Yes
	Galactic rotation	No	No, Yes