Precision Analysis of Solar Astrometric Positions from the JPL DE431 Ephemeris

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Abstract. The DE (Development Ephemeris) series of planetary ephemeris released by NASA’s Jet Propulsion Laboratory (JPL) have been widely used in deep-space navigation, interplanetary exploration, analysis and reduction of high-precision astronomical observations, and calibrations of gravitational theories etc. This work takes solar astronomic positions as an example to analyze precision of the JPL DE431 planetary ephemeris data. The results show that the DE431 ephemeris has high precision, which can be guaranteed within 0.08 milliarcseconds (mas), and can be used to carry out high-precision calculation of planetary positions.

1. Introduction

The planetary ephemeris of solar system is important for astrometry, deep-space navigation, interplanetary exploration, verification of gravitational theories, TT & C (telemetry, tracking & command) of aircraft, and other related disciplines and scientific research work. Currently, the dominant planetary ephemeris is the DE (Development Ephemeris) series of planetary ephemeris released by NASA’s Jet Propulsion Laboratory (JPL), which is based on a complete set of dynamic theory and data processing software. The numerical ephemeris has been widely used. The JPL has a long-term stable research and development team to continue this work. Combined with new observational data, the ephemeris is still being updated and developed continuously [1 - 4]. There are other planetary ephemeris of solar system include the France’s INPOP (Integrateur Numérique Planétaire de l’Observatoire de Paris) series, the Russia’s EMP (Ephemeris of Planets and the Moon) series and the Swiss Ephemeris. Long-term ephemeris research is mainly carried out by the Institute of Applied Astronomy of the Russian Academy of Sciences, and the independent EMP series ephemeris has been established.

In April 2013, the JPL released the DE431 planetary ephemeris covering from JED -3100015.5 (-13200 August 15) to JED 8000016.5 (17191 March 15), the corresponding reference frame adopts the International Celestial Reference Frame (ICRF) [3, 4]. Solar astrometric positions is taken as an example, precision of the JPL DE431 ephemeris data is investigated in this present paper.

2. Analysis Method

The Swiss Ephemeris is a high-precision ephemeris developed by Astrodienst, which is mainly based on the JPL DE series ephemeris. The original version was based on the DE405/406 ephemeris in 1997. Since the release of version 2.00 in February 2014, it is based on the DE431 ephemeris released by the
JPL in 2013 [5, 6]. The ephemeris provides a package of functions for calculating positions of some celestial bodies. It contains three types of ephemeris data including the raw JPL DE431 data, the Swiss ephemeris data (default value) or data from Steve Moshier’s built-in semi-analytic theory.

The JPL Horizons online ephemeris system provides a way to obtain online data of solar system celestial bodies and high-precision ephemeris [7]. The system is provided by the JPL’s solar system dynamics group.

In this work, with the original JPL DE431 ephemeris data, the Swiss Ephemeris program is used to calculate astrometric positions of the sun, with ephemeris on investigating positional precision of celestial bodies, combining the online ephemeris system of the JPL Horizons.

3. Precision Analysis
As mentioned previously, the JPL DE431 can be used to calculate positions of the sun at any time between -13200 and 17191. However, the JPL Horizons online ephemeris system can only calculate solar positions between -9997 and 9999, and the unit of time step can be minute, hour, day, year, etc. In order to compare the precision conveniently, the Swiss ephemeris and the JPL Horizons online ephemeris system are used to calculate astrometric position (right ascension: RA and declination: DEC) of the sun under the International Celestial Reference Frame (ICRF) and the J2000.

The calculation time span and time step are the minute value from March 1 to March 31 2021, the hourly value from January 1 2021 to December 31 2025, the daily value from January 1 2000 to December 31 2099 and the annual value from -9997 to 9998. The Terrestrial Time (TT) is used during calculating positions. The numerical difference obtained by the above two methods are plotted in the Figures 1-4. Here, the unit of the difference is adopted with milliarcsecond (mas).

![Figure 1. The difference of solar astrometric positions from March 1 to March 31, 2021 (minute value)](image-url)
Figure 2. The difference of solar astrometric position from January 1 2021 to December 31 2025 (hourly value)

Figure 3. The difference of solar astrometric position from January 1 2000 to December 31 2099 (daily value)
As for the above analysis results, the minimum, maximum and standard deviation of the difference for right ascension and declination are obtained and listed in the Table 1.

| Period        | step          | Min ΔRA mas | Max ΔRA Mas | STD ΔRA Mas | Min ΔDEC mas | Max ΔDEC mas | STD ΔDEC mas |
|---------------|---------------|-------------|-------------|-------------|--------------|--------------|-------------|
| 2021.03       | Minute        | -0.054      | 0.046       | 0.0291      | -0.080       | 0.080        | 0.0380      |
| 2021-2025     | Hour          | -0.054      | 0.054       | 0.0289      | -0.080       | 0.080        | 0.0334      |
| 2000-2099     | Day           | -0.054      | 0.054       | 0.0290      | -0.080       | 0.080        | 0.0335      |
| -9997-9999    | year          | -0.054      | 0.054       | 0.0290      | -0.080       | 0.080        | 0.0323      |

It is can be seen that the DE431 planetary ephemeris and the JPL Horizons online ephemeris have very close precision within the above statistical time periods. Specifically, the maximum difference of right ascension is 0.054 mas, and the corresponding standard deviation is 0.0291 mas; the maximum difference of declination is 0.08 mas, and the corresponding standard deviation is 0.0380 mas.

4. Conclusion
This work takes the solar astrometric positions as an example to analyze precision of the JPL DE431 planetary ephemeris. The results show that the DE431 ephemeris has high precision. Compared with the JPL Horizons online ephemeris, the maximum difference of right ascension for the DE431 ephemeris is 0.054 mas, and the corresponding standard deviation is 0.0291 mas; the maximum difference of declination for the DE431 ephemeris is 0.08 mas, and the corresponding standard deviation is 0.0380 mas. This ephemeris can be used to carry out high-precision solar position calculations.
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