Comparison and Analysis of Solar Position from Three Astronomical Planetary Ephemeris

Lihua Ma*, Xiaolan Wang, Chao Hu and Qiyuan Qiao

National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China
*Corresponding author e-mail: mlh@nao.cas.cn

Abstract. Some astronomical phenomena including eclipse, transit, planetary conjunction and opposition are closely related to position of the Sun. Solar position directly determines the time when these phenomena occur. The premise of calculating these phenomena is to calculate the solar position. With astronomical planetary ephemeris, the solar position at any one time can be obtained. In this present paper, three astronomical ephemeris is used to calculate the solar position, with emphasis on position difference of the Sun. The results show remarkable inconsistencies existing in three ephemeris. The maximum difference of right ascension and declination for the Sun reaches 45 arcseconds and 41 arcseconds, respectively.

1. Introduction

The Sun, one of the important celestial bodies in the solar system, has the closest relationship with activity of human beings. Solar position directly relates to some astronomical phenomena including eclipse, transit, planetary conjunction and opposition. Eclipse embodies relationship of shielding each other between the Sun, the Moon and the Earth. The transit means that one celestial body is blocked by another small celestial body. The small celestial body is usually a solar system planet. Planetary conjunction means the celestial body is in the same direction as the Sun. The celestial body rises and falls with the Sun. Planetary opposition is the difference between position of the celestial body and the Sun observed on the Earth, 180 degrees, that is, the phenomenon of the celestial body and the Sun on both sides of the Earth. The premise of calculating these astronomical phenomena is to calculate the solar position. Currently, making full use of solar energy is becoming one of important engineering applications. It also requires the solar position. Astronomical ephemeris that can be used to calculate position of the planet is provided. With the astronomical ephemeris, the position of some planets can be accurately calculated. In this work, with three astronomical ephemeres, the solar position is calculated and position differences from the three ephemereis is investigated.

2. Astronomical Planetary Ephemeris

Bretagnon and Simon proposed a calculation program for position of major planets, which can be used to calculate position of the planet from 4000 B.C. to A.D. 2800 [1]. This program can also give spatial coordinates of the Sun. Simplicity, this method is referred to as the BS86 in the following analysis.

The Bureau des Longitudes in Paris developed a semi-analytical planetary theory describing major planets ephemeris which introduced the VSOP (Variations Sécuaires des Orbites Planétaires) concept to describe long-term change in orbit of major planets such as Mercury to Neptune. The first version of the model called as VSOP82, only gives orbital parameters at any time. The updated edition,
VSOP87 model improves accuracy. With the model, someone obtains orbital parameters of the planet at any time and directly calculates the planetary position [2].

The Jet Propulsion Laboratory (JPL) developed a set of planetary ephemeris, with an abbreviation JPL DE (number) or DE (number). The DE405 and DE406 were released in 1997, 1998, respectively. The DE405 covers from A.D. 1599 to A.D. 2201. In order to cover a longer period of time, meanwhile, to reduce the size of the ephemeris file, the DE406 removes nutation and libration effects from the DE405, and slightly reduces interpolation polynomial accuracy. Finally the DE406 covers from 3000 B.C. to A.D. 3000. After that, the JPL released a few editions. A slight difference exists in different JPL ephemeris editions [3]. Considering that the JPL planetary ephemeris is released relatively late and with higher accuracy, many astronomical calculations mainly are based on the JPL ephemeris.

3. Solar Apparent Position
Usually, the position of some celestial body is described with true position and apparent position. The true position gives real spatial position of the celestial body. The apparent position gives position of the celestial body observed by the observer. During calculating the apparent position, some factors including geographical location of the observer, aberration, precision and nutation should be considered [4-7]. As course, the apparent position is more meaningful to the observer. The geocentric position is position of the celestial body assumed to be observed by the observer at the Earth’s center. Here the position of the Sun’s geocentric view is calculated in the geocentric coordinate frame. The corresponding foundational elements are right ascension (α) and declination (δ).

4. Comparison and Analysis of Solar Position
The Terrestrial Time (TT) is a modern astronomical time standard defined by the International Astronomical Union (IAU). The Ephemeris Time (ET), the Terrestrial Dynamical Time (TDT) and the TT can be converted to each other. In this work, the TT is selected as time reference.

Firstly 3000 B.C. to A.D. 3000 are chosen as the analysis span, right ascension (α) and declination (δ) of the Sun with an hourly interval are calculated in the following seven time periods: 3000 B.C. – 2950 B.C., 2000 B.C. – 1950 B.C., 1000 B.C. – 950 B.C., A.D. 0 – A.D. 50, A.D. 1000 – A.D. 1050, A.D. 2000 – A.D. 2050 and A.D. 2950 – A.D. 3000. Setting the JPL DE406 ephemeris as a reference, then subtracting DE406 from BS86 and VSOP87 respectively. The results are plotted in the Figures. 1-7. Statistics results are list in Table 1.
Figure 1. Difference of solar position between BS86 and DE406, and VSOP87 and DE406 from 3000 B.C. to 2950 B.C.

Figure 2. Difference of solar position between BS86 and DE406, and VSOP87 and DE406 from 2000 B.C. to 1950 B.C.
Figure 3. Difference of solar position between BS86 and DE406, and VSOP87 and DE406 from 1000 B.C. to 950 B.C.

Figure 4. Difference of solar position between BS86 and DE406, and VSOP87 and DE406 from A.D. 0 to 50 A.D.
Figure 5. Difference of solar position between BS86 and DE406, and VSOP87 and DE406 from A.D. 1000 to A.D. 1050.

Figure 6. Difference of solar position between BS86 and DE406, and VSOP87 and DE406 from A.D. 2000 to A.D. 2050.
Figure 7. Difference of solar position between BS86 and DE406, and VSOP87 and DE406 from A.D. 2950 to A.D. 3000

Table 1. Difference of solar position between BS86 and DE406, VSOP87 and DE406

| Time period    | Type   | BS86 – DE406 | VSOP87 – DE406 |
|---------------|--------|--------------|----------------|
|               |        | Δα (arcsecond) | Δδ (arcsecond) | Δα(arcsecond) | Δδ (arcsecond) |
| 3000 B.C. - 2950 B.C. | Min    | -25.49        | -33.99         | -44.23        | -40.62         |
|               | Max    | -5.78         | 34.52          | 4.64          | 41.27          |
|               | Mean   | -15.44        | -0.46          | -18.98        | -0.456         |
| 2000 B.C. - 1950 B.C. | Min    | -25.87        | -16.05         | -43.20        | -21.89         |
|               | Max    | -14.90        | 16.49          | -2.21         | 22.35          |
|               | Mean   | -20.36        | -0.15          | -22.36        | -0.10          |
| 1000 B.C. - 950 B.C. | Min    | -26.89        | -11.49         | -44.55        | -17.09         |
|               | Max    | -18.04        | 11.88          | -4.21         | 17.39          |
|               | Mean   | -22.59        | -0.05          | -21.91        | -0.03          |
| A.D. 0 - A.D. 50 | Min    | -27.70        | -10.58         | -45.41        | -16.55         |
|               | Max    | -19.22        | 10.61          | -4.64         | 16.48          |
|               | Mean   | -23.33        | -0.04          | -23.06        | -0.11          |
| A.D. 1000 - A.D. 1050 | Min   | -26.46        | -10.09         | -44.23        | -16.10         |
|               | Max    | -18.95        | 10.19          | -3.40         | 15.92          |
|               | Mean   | -22.35        | 0.00           | -23.78        | -0.06          |
| A.D. 2000 - A.D. 2050 | Min    | -23.81        | -9.67          | -42.34        | -15.48         |
|               | Max    | -17.23        | 9.06           | -1.03         | 15.20          |
|               | Mean   | -20.40        | 0.03           | -20.55        | 0.02           |
| A.D. 2950 - A.D. 3000 | Min    | -20.57        | -8.07          | -38.56        | -14.36         |
|               | Max    | -13.82        | 7.91           | 3.08          | 14.00          |
|               | Mean   | -17.11        | -0.02          | -17.20        | 0.03           |
5. Results and Discussion
In this work, solar position during 3000 B.C. to A.D. 3000 is calculated with three astronomical planetary ephemeris. The results show the remarkable difference existing in these ephemeris. Here taking the JPL DE406 ephemeris as a reference, the maximum differences of solar right ascension and declination from Bretagnon and Simon’s method reach 28 arcseconds and 35 arcseconds, respectively. The maximum differences of solar right ascension and declination from VSOP87 model reach 45 arcseconds and 41 arcseconds, respectively.

Obviously, there is a relatively close maximum variation amplitude in right ascension and declination obtained by Bretagnon and Simon’s method and VSOP87 model. Meanwhile, right ascension and declination from VSOP87 has a significant period of about 20 years, which is consistent with original intention of the Bureau des Longitudes in Paris to develop the model. There are significant short period entries in the Bretagnon and Simon’s method and VSOP87 model. The short period term of right ascension and declination is mainly semi-annual change, annual change, respectively. It should be noted that the position difference from these planetary ephemeris is acceptable to conventional observations.

Acknowledgements
This work was financially supported by National Natural Science Foundation of China (11573041). The authors were grateful to the Wikipedia Encyclopedia (https://en.wikipedia.org/wiki/Main_Page) for helpful documentation.

References
[1] P. Bretagnon and J. Simon, Planetary Programs and Tables from -4000 to +2800, Willmann-Bell, Inc, 1986.
[2] P. Bretagnon and G. Francou, Planetary theories in rectangular and spherical variables. VSOP87 solutions, Astronomy & Astrophysics, 202 (1988) 309-315.
[3] W. Lei, K. Li and H. Zhang, Structure, calculation and comparison of development ephemerides, Journal of Spacecraft TT&C Technology. 35 (2016) 375-384.
[4] J. Meeus, Astronomical Formulae for Calculators, Willmann-Bell, Inc, 1982.
[5] J. Meeus, Astronomical Algorithms, second ed., Willmann-Bell, Inc, 1998.
[6] G. Kaplan, J. Bartlett, A. Monet, J. Bangert and W. Puatua, User’s guide to NOVAS version F3.1, U.S. Naval Observatory, 2011.
[7] D. Vallado, Fundamentals of Astrodynamics and Applications, fourth ed., Microcosm Press, 2013.