Reprint of Universal Time Corrections Derived from Central Eclipse Observations on January 13, 1507

Authors: Ma Lihua

Date: 2022-06-16T00:00:00+00:00

Abstract

The Tongling County Annals of Anhui from the Qianlong period of the Qing Dynasty contains observational records of a central eclipse (a general term for total and annular solar eclipses) that occurred in January 1507 (the second year of the Zhengde era of the Ming Dynasty). The authors of this paper utilized modern astronomical planetary ephemerides to calculate the eclipse path of this solar eclipse and to investigate the Universal Time correction for that period. By combining observational records regarding this solar eclipse from two local gazetteers—the Dongxiang County Annals of Jiangxi from the Jiajing period of the Ming Dynasty and the Wangjiang County Annals of Anhui from the Shunzhi period of the Qing Dynasty—the observability conditions of this solar eclipse in Dongxiang County and Wangjiang County were further analyzed. This research holds certain reference value for studies of the long-term variation of Earth' s rotation.

Full Text

A Delta-T Value from the Record of Central Eclipse on January 13, 1507

Ma Lihua
National Astronomical Observatory, Chinese Academy of Sciences, Beijing 100101, China
Email: mlh@nao.cas.cn

Abstract

The Qing Dynasty Qianlong Anhui Tongling County Chronicle contains an observation record of a central eclipse (a collective term for total and annular solar

eclipses) that occurred in January 1507 (the 2nd year of the Zhengde reign of the Ming Dynasty). Using modern astronomical planetary ephemerides, this study calculates the eclipse path of this solar eclipse to investigate the Universal Time correction at that time. Combined with observation records of this eclipse in the Ming Dynasty Jiajing Jiangxi Dongxiang County Chronicle and the Qing Dynasty Shunzhi Anhui Wangjiang County Chronicle, the observable conditions of this eclipse in Dongxiang and Wangjiang counties are further analyzed. The results of this research provide valuable reference for studies on the secular variation of Earth' s rotation.

Keywords: central eclipse; solar eclipse observation records; Universal Time correction

Ancient Chinese astronomical observation records hold significant value for historical research and ancient astronomy studies, playing an important role in modern astronomical research [1-3]. Chinese local chronicles are documentary literature that comprehensively and systematically describe the natural, political, economic, cultural, and social history and current status of their administrative regions. Numerous ancient local chronicles contain dedicated textual records of celestial phenomena (including solar eclipses, lunar eclipses, lunar occultations, oppositions, conjunctions, etc.), providing important observational data for astronomical research. Typically, these chronicles describe celestial observations in words, but such records are subjective and may contain errors or omissions during transmission. Consequently, caution must be exercised when verifying these records for scientific research.

It is well known that Earth' s rotation exhibits a long-term deceleration trend. The secular variation of Earth' s rotation can be studied using ancient astronomical observation records, and many scholars have conducted research in this area [4-16]. The Qing Dynasty Qianlong Anhui Tongling County Chronicle, Volume 13, page 5, records: "(Ming Dynasty Zhengde 2nd year) First month, new moon, solar eclipse, ji." Here, "Ming Dynasty Zhengde 2nd year" corresponds to 1507, and "ji" is the specialized term in ancient Chinese astronomical records for observing a central eclipse (collectively referring to total and annular solar eclipses). This concise record describes a central eclipse observed in Tongling County, Anhui. Additionally, both the Ming Dynasty Jiajing Jiangxi Dongxiang County Chronicle and the Qing Dynasty Shunzhi Anhui Wangjiang County Chronicle contain textual records of a solar eclipse observed in January 1507. This study utilizes the DE422 modern astronomical planetary ephemeris released by NASA' s Jet Propulsion Laboratory (JPL) to analyze that this eclipse record corresponds to the solar eclipse event on January 13, 1507. The following sections present detailed calculations of the eclipse path distribution and investigate the Universal Time correction and secular variation of Earth' s rotation.

1 The Solar Eclipse on January 13, 1507 in the Terrestrial Dynamical Time System

Astronomical planetary ephemerides are of great practical value for astronomy, Earth sciences, and related disciplines. The DE series modern astronomical planetary ephemerides released by JPL have been widely applied in astrometry, deep space navigation, and interplanetary exploration. The DE422 planetary ephemeris was released by JPL in September 2009 [17], spanning from December 7, 3001 BCE to January 30, 3000 CE, which meets the basic requirements for studying ancient astronomical records. The DE422 ephemeris adopts the International Celestial Reference System (ICRS) recommended by the International Astronomical Union (IAU), with the corresponding International Celestial Reference Frame (ICRF) realized through a set of extragalactic radio source positions. The DE422 ephemeris employs Terrestrial Dynamical Time (TDT), a uniform time system.

A solar eclipse is a special astronomical phenomenon that occurs when the Moon moves between the Sun and Earth, and the Moon' s shadow falls precisely on Earth' s surface. Using astronomical planetary ephemerides, the spatial positions of the Sun and Moon in the TDT system can be calculated. Based on the geometric relationship between the Sun and Moon, the observability of the solar eclipse on Earth' s surface—i.e., the eclipse path—can be determined. Calculations show that the solar eclipse on January 13, 1507 was an annular eclipse. The corresponding eclipse path is plotted in Figure 1. In the figure, the narrow strip enclosed by red dashed lines represents the region on Earth' s surface where the annular eclipse could be observed.

[Figure 1: see original paper]

2 Universal Time Correction Obtained from Observation Records of the Solar Eclipse on January 13, 1507

In reality, Earth' s rotation exhibits a significant long-term deceleration trend. There exists a time correction between the TDT system and Universal Time (UT), known as the Universal Time correction ΔT:

$\Delta T = TDT\text{-}UT$

This equation gives the conversion relationship between TDT and UT, with ΔT directly reflecting the long-term variation of Earth' s rotation. Using ancient astronomical observation records in the UT system, the ΔT value for the epoch of the phenomenon can be deduced. Conversely, knowing the ΔT value for the epoch of an ancient astronomical phenomenon allows the calculation of its observability at that time [18-19].

The textual record of a central eclipse observed on January 13, 1507 in Tongling County, Anhui (30°.93N, 117°.82E) indicates that Tongling County was located within the narrow strip where the central eclipse was visible. Based on this,

the upper and lower limits of the ΔT value can be determined as [294s, 1518s]. That is, when ΔT falls within this range, a central eclipse could be observed in Tongling County.

For the observation of the solar eclipse on January 13, 1507, both the Ming Dynasty Jiajing Jiangxi Dongxiang County Chronicle and the Qing Dynasty Shunzhi Anhui Wangjiang County Chronicle also contain records. Both chronicles used the phrase "solar eclipse, shen" to describe the observed phenomenon. Here, combining the aforementioned upper and lower limits of ΔT, the observable conditions of this eclipse in Dongxiang County, Jiangxi (28°.23N, 116°.61E) and Wangjiang County, Anhui (30°.12N, 116°.69E) are analyzed.

Tables 1 and 2 present the TDT times, solar altitude angles, and magnitudes (quantitative values describing eclipse extent) for each eclipse phase observed at these two locations. For clarity, the tables also provide the corresponding local times (LT). Considering that the final contact of the eclipse occurred after sunset at both locations, the sunset times are also included in the tables.

As shown in Tables 1 and 2, the magnitude of the solar eclipse observed in Dongxiang County, Jiangxi on January 13, 1507 ranged between 0.881 and 0.945, while in Wangjiang County, Anhui it ranged between 0.930 and 0.947, both representing large partial eclipses. Had weather conditions permitted, local observers would have significantly perceived this eclipse phenomenon and recorded it in their local chronicles. This indirectly validates the correctness of the ΔT range obtained in this study.

Morrison and Stephenson comprehensively utilized ancient astronomical observation records from multiple locations to provide piecewise formulas for calculating ΔT for different periods [14]. Espenak and Meeus further provided correction methods corresponding to different astronomical planetary ephemerides [20]. Based on these, the calculated ΔT value for January 13, 1507 is 188s$±$20s, which differs from the ΔT value obtained in this study based on the Tongling County Chronicle (with a minimum difference of 86s). Morrison and Stephenson did not consider the total solar eclipse record in the Tongling County Chronicle when formulating their piecewise formulas, and the results of this study can be used to update the parameters of these functions. However, considering that observation records in local chronicles may contain errors during transmission, even with corroborating evidence, the accuracy of the "ji" record from Tongling cannot be completely guaranteed.

This study combines the observation record of the solar eclipse on January 13, 1507 from the Qing Dynasty Qianlong Anhui Tongling County Chronicle to confirm the observed central eclipse phenomenon and calculates the Universal Time correction ΔT range as [294s, 1518s]. Further investigation of the observation records in the Ming Dynasty Jiajing Jiangxi Dongxiang County Chronicle and the Qing Dynasty Shunzhi Anhui Wangjiang County Chronicle confirms that both locations could observe large-magnitude partial eclipses. This work provides valuable reference for research on the secular variation of Earth' s rotation.

Additionally, the results of this study show a small difference from the ΔT formula provided by Morrison and Stephenson, and future work will investigate the reasons for this discrepancy.

References

[1] Liu C.Y. Ancient astronomical observation and applied historical astronomy. Publlications of the Shanxi Astronomical Observatory, 1990, 13(1), 1-8.

[2] Han Y.B. Principle and method to study secular variation of the Earth' s rotation using observations of ancient astronomical events. Journal of Beijing Normal University (Natural Science), 2001, 37(1), 26-30.

[3] Feng S. Astroarchaeology in China (3rd Ed). Beijing: China Social Sciences Press, 2017.

[4] Han Y.B., Li Z.S., Lin B.S., Yang X.H. The parameter of variation in the rotational speed of the Earth from ancient central eclipse records of China. ACTA Astrophysica Sinica, 1984, 4(2):107-114.

[5] Han Y.B., Li Q.B., Chao, B.F. Records of ancient solar and lunar eclipses and study of variation of the Earth' s rotation. Progress in Geophysics. 1995, 10(3), 43-50.

[6] Han Y.B. Two interesting phenomena in variation of the Earth' s rotation derived from studies of records of ancient astronomical observations. Progress in Geophysics, 1996, 11(4): 116-118.

[7] Han Y.B., Qiao Q.Y. A Check on the Variations of Earth' s Rotation with an Ancient Solar Eclipse. Chin. J. Astron. Astrophys. 2003, 3(6), 569–575.

[8] Wu S.X., Liu C.Y. The progress on the research of the secular variation of the Earth' s rotation by the ancient eclipses records. Progress in Astronomy. 1987, 5(2), 147-157.

[9] Pang K.D., Yau K., Chou Hh., Wolff R. Computer analysis of some ancient Chinese sunrise eclipse records to determine the Earth' s rotation rate. Vistas in Astronomy. 1988, 31: 833-847.

[10] Zhang P.Y., Han Y.B. The timing solar eclipses records recorded in China and the secular changes in the Earth' s rotation before the 8th century. ACTA Astronomica Sinica, 1995, 36(3), 314-320.

[11] Stephenson F.R. Historical Eclipses and Earth' s Rotation. Cambridge, UK: Cambridge University Press, June 1997.

[12] Stephenson F.R. Historical eclipses and Earth' s rotation. Astronomy & Geophysics, 2003, 44(2), 2.22–2.27

[13] Stephenson F.R., Morrison L.V., Hohenkerk C.Y. Measurement of the Earth' s rotation 720 BC to AD 2015. 2016, Proc. Roy. Soc. A, 2016, 472, 2016.0404

[14] Morrison L.V., Stephenson F.R., Historical Values of the Earth' s Clock Error ΔT and the Calculation of Eclipses, J. Hist. Astron., 2004, 35(120), 327-336.

[15] Morrison L.V., Stephenson F.R., Hohenkerk C.Y., Zawilski M. Addendum 2020 to 'Measurement of the Earth' s rotation: 720 BC to AD 2015' .Proc. R. Soc. A. 2021, 477: 20200776.

[16] Tanikawa K., Sôma M. ΔT and the tidal acceleration of the lunar motion from eclipses observed at plural sites, Publ. Astron. Soc. Japan. 2004, 56, 879-885.

[17] Konopliv S, Asmar S W, Folkner W M, et al. Mars high resolution gravity fields from MRO, Mars seasonal gravity, and other dynamical parameters[J]. Icarus, 2011, 211: 401–428.

[18] Ma L H, Han Y B, Yin Z Q, et al. Research on Zhongkang solar eclipse based on modern astronomical planetary ephemeris [J]. Astronomical Research & Technology. 2021a, 18(3), 421-426.

[19] Ma L H, Han Y B, Qiao Q Y, Sun X Z. Research on Lunar Eclipses in the Yin Period Oracle Bone Inscription Based on Modern Astronomical Planetary Ephemeris [J]. Astronomical Research & Technology. 2021b, 18(4), 561-566.

[20] Espenak F, Meeus J. Five millennium catalog of solar eclipses –1999 to +3000 (2000 BCE to 3000 CE)-revised. NASA-TP2009–214174. http://ntrs.nasa.gov/citations/20090028005.

Note: Figure translations are in progress. See original paper for figures.