HISTORICAL ECLIPSES AND EARTH'S ROTATION

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Determination of changes in the length of the day

14.1 Introduction

In chapters 4–13, more than 400 timed and untimed observations of both solar and lunar eclipses from the pre-telescopic period (date range -700 to +1600) have been investigated in detail. ΔT values or limits (depending on whether the observations were timed or untimed) have been derived in almost every case. The fundamental objective of the present chapter is to use these results to obtain the best-fitting ΔT curve to the data and hence to determine changes in the length of the day (COD) over the historical period. In addition, the various geophysical mechanisms responsible for the observed variations will also be discussed. I am grateful to Dr L. Y. Morrison of the Royal Greenwich Observatory for undertaking the data analysis which forms the basis of much of this chapter and producing several of the diagrams. This chapter is essentially an enlargement of section 5 of the paper by Stephenson and Morrison (1995). Although several tens of further historical data have been added (notably medieval Chinese timing – see chapter 9), the basic conclusions obtained is that paper remain unchanged.

All of the ΔT results derived in chapters 4-13 are summarised in tabular form in the Appendices for ready reference. For each individual observation, only the year (− or +) and appropriate ΔT value or limits are tabulated. Appendix A contains timed data and Appendix B untimed material, each being divided into sub-groups depending on the source and type of observation it contains. An outline of the contents of each sub-group is as follows:

A2. Babylonian timings of solar eclipses (intervals > 25 deg).

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A4. Chinese measurements of solar eclipse times to 1/100 day (+ estimates of phase on horizon).

A5. Chinese measurements of lunar eclipse times to 1/3 night-watch (+ estimates of phase on horizon).

A6. Chinese measurements of lunar eclipse times to 1/10 day.

A7. Ancient Greek timings of lunar and solar eclipses.

A8. Arab timings of solar eclipses.

A9. Arab timings of lunar eclipses.

B1. Untimed total and annular solar eclipses.


B3. Sunrise/sunset or moonrise/moonset observations.

Estimates of the degree of obscuration of the Sun or Moon when on the horizon are ranked with timed observations since they yield results of similar form. The total numbers of timed and untimed data listed are respectively about 305 and 105.

14.2 Timed and untimed observations

As these two groups form independent data sets, the \Delta T values determined from them can be considered separately. The results in Appendix A are largely derived from individual timings by astronomers of the various stages of solar or lunar eclipses. Since each measurement leads to a specific value for \Delta T (rather than a limit), the results can be treated statistically. In the analysis of this material, the \Delta T values in each group will be assigned unit weight except for data in categories A1 and A8. The results derived from Babylonian records in which the measured time-interval was less than 25 deg (group A1) and also Arab timings of solar eclipses (A8) show an unusually high degree of self-consistency even when the observations were said to be only approximate. Hence they will be allotted double weight. Although the Arab observations originated from several independent sources, it seems best to regard them as a unit. None of the data in Appendix B are based on measurement. Here the observers, many of whom were not astronomers, simply described what they saw — sometimes in graphic terms. Untimed observations set limits on \Delta T. Unless the observations are questionable in any way, a viable \Delta T curve should not infringe these limits. Nevertheless, the form of the results in each of the three categories B1, B2 and B3 have certain
Fig. 14.1 $\Delta T$ ranges obtained from unlimted total, annular and partial solar eclipses and also solar and lunar eclipses on the horizon: $-800$ to $+1600$. Also shown (inset) is the $\Delta T$ curve obtained from modern occultations. (Courtesy: Dr. L.V. Morrison.)

Fig. 14.2 $\Delta T$ values obtained from timed solar and lunar eclipses. Also shown (inset) is the $\Delta T$ curve obtained from modern occultations. (Courtesy: Dr. L.V. Morrison.)
Also shown in both figure 14.1 and figure 14.2 (inset, on a much larger scale) is the $\Delta T$ curve since the year +1600, obtained mainly from telescopic observations of occultations (Stephens and Morrison, 1984). This is depicted as an irregular full line. The nature of the four smooth curves will be discussed below.

It is obvious from comparison of figures 14.1 and 14.2 that the un timed and timed data define similar trends in $\Delta T$ over the past 2700 years. This is particularly clear from figure 14.3, which displays both the timed and un timed data. In this diagram, each individual $\Delta T$ value is represented by a dot of equal size. Each allowed $\Delta T$ range as indicated by a total or annular solar eclipse or a horizon observation is denoted by a gap between two vertical lines. In the case of a partial solar eclipse, almost the entire solution space is permitted except for that indicated by a short vertical line. This method of depicting $\Delta T$ limits was suggested to me by Dr R. S. Roberts of the University of Durham, to whom I am grateful for producing figure 14.3. The convention adopted is the reverse of that followed in figure 14.1.

In the following sections, the timed and un timed data will be used to assess the viability of the following assumptions: i) lunar and solar tidal...
The accord between the parabola represented by equation (14.3) and the observational results is closer in ancient times, but fewer $\Delta T$ limits are critical. Figure 14.5 displays the limits set by the untimed data over the period from $-800$ to $+500$ on an enhanced scale.

By choosing a different origin for the curve of the parabola and varying the quadratic term, it is possible to obtain a better fit to the set of pre-telescopic data. However, this is at the expense of the modern observations. Stephenson and Morrison (1995) found that the following parabola fitted the ancient and medieval observations more closely than equation (14.3):

$$\Delta T = 357^2 - 20 \text{sec},$$

with $T$ measured in centuries from a cusp at the epoch $+1735$. However, they remarked that this parabola does not remotely resemble the $\Delta T$ curve between $+1600$ and the present. In addition, it does not meet the condition that the cusp lie near the beginning of the nineteenth century, keeping with the requirement that the average LOD at that epoch should be equal to the standard LOD on the TT scale — see chapter 1.

It is thus apparent that no single parabola can satisfactorily represent both the pre-telescopic and telescopic data, implying that the non-tidal component of the Earth's spin is variable with time. The degree of variability will be investigated in the following section by fitting a more flexible curve than a parabola to the data.
Fig. 14.5 ΔT limits obtained from un timed total, annular and partial solar eclipses and also solar and lunar eclipses on the horizon: -800 to +700. (Courtesy: Dr L. V. Morrissey.)