HISTORICAL ECLIPSES AND EARTH'S ROTATION

F. Richard Stephenson
University of Durham

1997

CAMBRIDGE
UNIVERSITY PRESS

14

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 (LOD) 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. V. 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 in 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:

A1. Babylonian timings of solar and lunar eclipses (intervals < 25 deg).

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

A3. Babylonian timings of lunar eclipses (intervals > 25 deg or approximate measurements < 25 deg + estimates of phase on horizon).

A4. Chinese measurements of solar eclipse times to $\frac{1}{100}$ day (+ estimates of phase on horizon).

A5. Chinese measurements of lunar eclipse times to $\frac{1}{5}$ night-watch (+ estimates of phase on horizon).

A6. Chinese measurements of lunar eclipse times to $\frac{1}{100}$ 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.

B2. Untimed partial solar eclipses (ΔT limits reversed).

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.

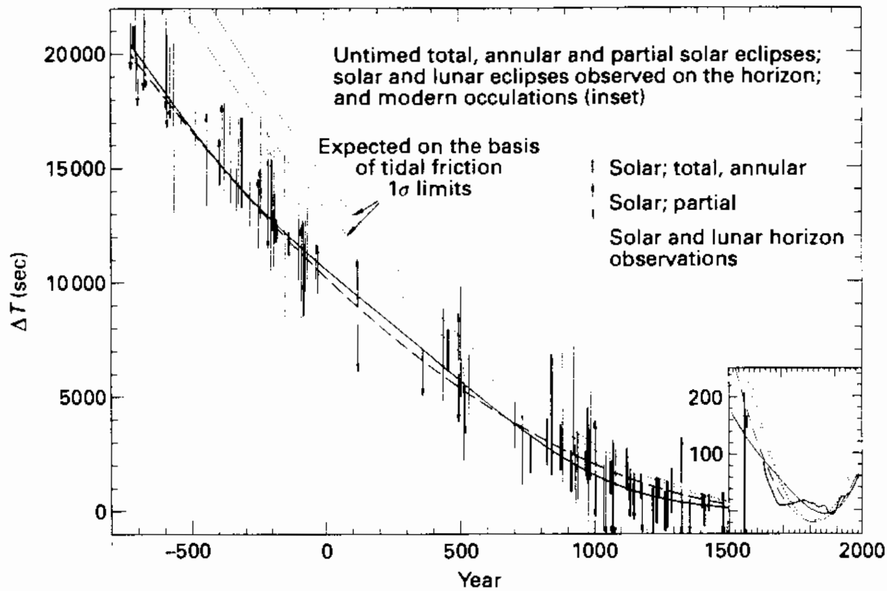

Fig. 14.1 ΔT ranges obtained from untimed total, annular and partial solar eclipses and also solar and lunar eclipses on the horizon: -800 to $+1600$. Also shown (inset) is the ΔT curve obtained from modern occultations. (Courtesy: Dr L. V. Morrison.)

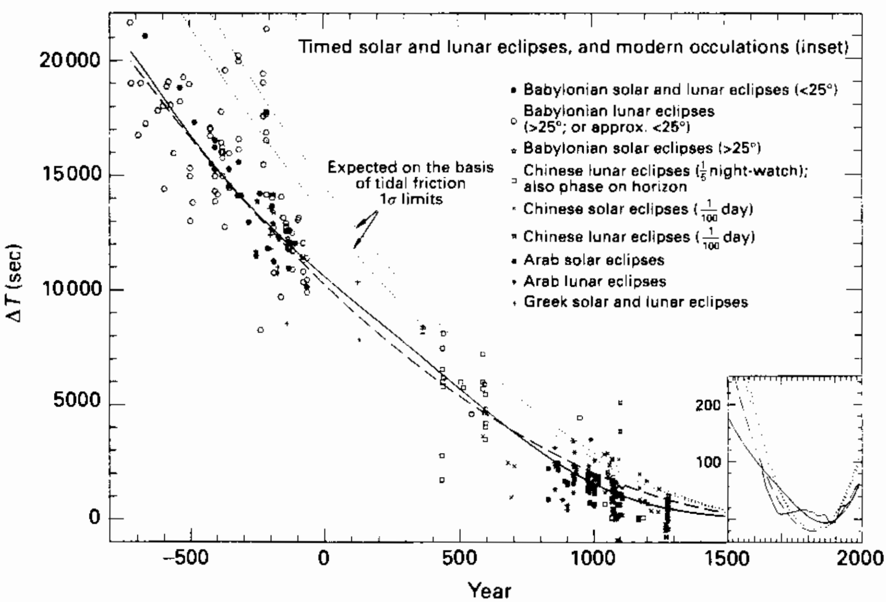

Fig. 14.2 ΔT values obtained from timed solar and lunar eclipses. Also shown (inset) is the ΔT curve obtained from modern occultations. (Courtesy: Dr L.V. Morrison.)

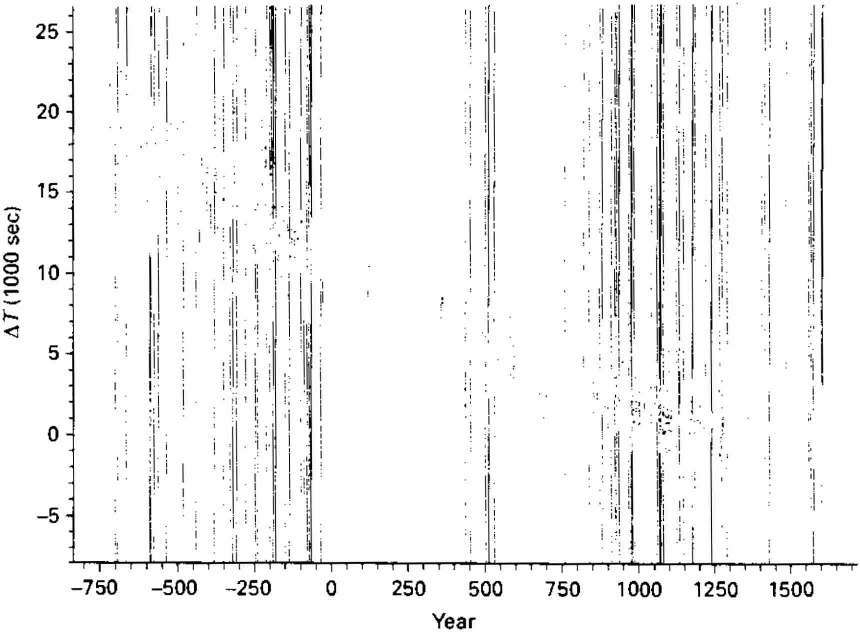

Fig. 14.3 ΔT ranges and individual values obtained from untimed and timed solar and lunar eclipses: −800 to +1600. In this diagram, each allowed ΔT range is indicated by a gap between two vertical lines; this convention in the opposite to that adopted in figures 14.1, 14.4 and 14.5. (Courtesy: Dr R. S. Roberts).

Also shown in both figure 14.1 and figure 14.2 (inset, on a much larger scale) is the ΔT curve since the year +1600, obtained mainly from telescopic observations of occultations (Stephenson 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 untimed and timed data define similar trends in ΔT over the past 2700 years. This is particularly clear from figure 14.3, which displays both the timed and untimed data. In this diagram, each individual ΔT value is represented by a dot of equal size. Each allowed ΔT 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 ΔT 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.

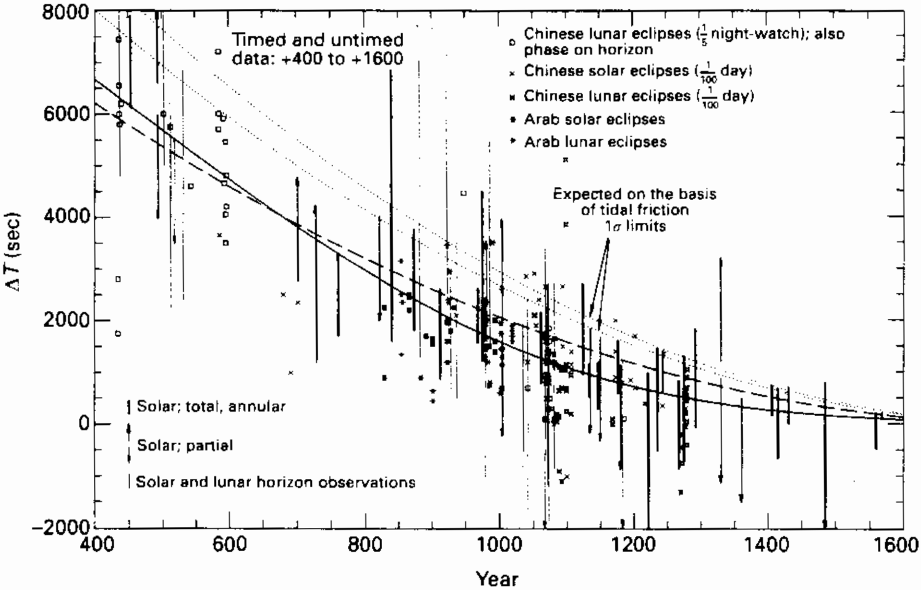

Fig. 14.4 Combined timed and untimed data for the period from +400 to +1600. (Courtesy: Dr L. V. Morrison.)

The accord between the parabola represented by equation (14.3) and the observational results is closer in ancient times, but fewer ΔT 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 cusp 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):

$$\Delta T = 35\tau^2 - 20\text{sec},$$

with τ measured in centuries from a cusp at the epoch +1735. However, they remarked that this parabola does not 'remotely resemble the ΔT 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, in 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.

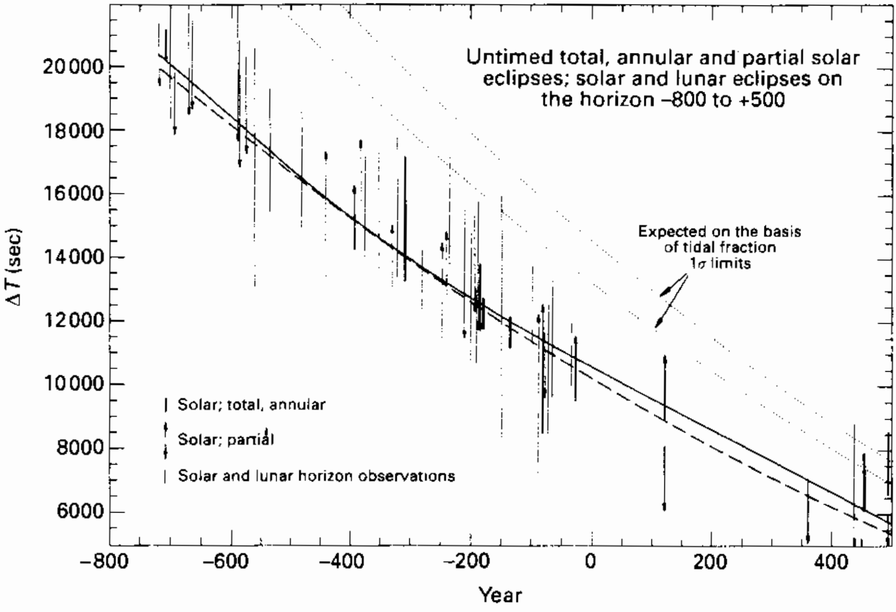

Fig. 14.5 ΔT limits obtained from untimed total, annular and partial solar eclipses and also solar and lunar eclipses on the horizon: −800 to +700. (Courtesy: Dr L. V. Morrison.)