HISTORICAL ECLIPSES AND EARTH'S ROTATION

F. Richard Stephenson
University of Durham

1997

CAMBRIDGE
UNIVERSITY PRESS

3.8.1 Total and annular solar eclipses

Throughout this investigation it will be assumed that an eclipse was only fully total or annular if a record clearly describes either the complete disappearance of the Sun or the reduction of the solar disk to a ring of light. As discussed in chapter 11, other effects – such as darkness or the visibility of stars – are only general indications of a very large eclipse. If the sky is clear, the onset of totality should be extremely well defined, as is evident from figure 3.5. This is confirmed by the impressions of modern observers (e.g. Muller, 1975; see also the many eighteenth and nineteenth century reports compiled by Ranyard, 1879). An interesting illustration is provided by the eclipse of AD 1715 May 3, which was total in England. Edmond Halley circulated advance notification of this eclipse throughout much of England, specifically asking those who happened to be near the edges of the belt of totality to keep a special watch. As a result, Halley (1715) was able to obtain several careful unaided-eye observations from near the northern and southern limits of totality. These reports proved to be so self-consistent that it has proved possible to use them to determine the mean solar semi-diameter within 0.1 arcsec (Parkinson *et al.*, 1988).

The following account, relating to the eclipse of AD 1241 Oct 6, is fairly typical of medieval descriptions of the total phase. It originates from the monastery of Stade in north Germany (see chapter 11):

> 1241 ... There was an eclipse of the Sun ... on the day before the Nones of October (Oct 6), on Sunday some time after midday. Stars appeared and the Sun was *completely* hidden from our sight ...

Use of the first person plural affirms that totality was witnessed in Stade.

In the case of an annular eclipse, the ring phase is less marked since a portion of the Sun stays unobscured at all times. Hence the loss of daylight is usually relatively small. Although more than 40 careful accounts of totality are preserved from various parts of the world in the pre-telescopic era, no more than four direct allusions to annularity can be traced in this period (AD 873, 1147, 1292 and 1601). Evidently, most events of this kind passed unnoticed. The ring phase is clearly described in the following brief report from Ta-tu (the former name for Beijing) on a date corresponding to AD 1292 Jan 21 (see also chapter 8):

> Chih-yuan reign period, 29th year, first month, day *chia-wu* [31]. The Sun was eclipsed. A darkness invaded the Sun, which was not totally covered. It was like a golden ring ...

Even if the Sun is only marginally reduced to a complete circle of light, the effect of irradiation is to greatly enhance visibility of this ring, as has been noted by modern observers. Immediately outside the zone

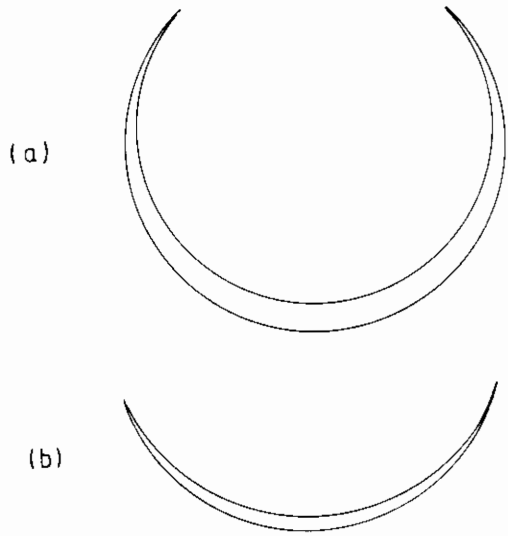

Fig. 3.8 Form of the crescent as seen just outside the central zone for a generally annular eclipse of typical central magnitude 0.95 (a) and a generally total obscuration of typical central magnitude 1.05 (b).

of annularity, the angle between the cusps of the crescent is small and remains less than 90 deg (i.e. making at least three-quarters of a full circle) even at some considerable distance from the central zone. This is illustrated in figure 3.8a, which is based on a typical central magnitude of 0.95. (By contrast, when a generally total obscuration is viewed from outside the umbral region this angle always exceeds 180 deg – see figure 3.8b.) Because of this feature, early descriptions of eclipses which were generally annular on the Earth's surface are often vague and difficult to interpret (e.g. 'a human head was seen in the Sun' – as reported from both Cologne and Hirschau in Germany in AD 1207 – see chapter 11). Hence unless a text clearly asserts that a full ring of sunlight was seen (or, on the contrary, likens the Sun to a crescent), the record is best rejected.

Provided it can be confidently established that a certain solar eclipse was fully total or annular on a definite date and at a specified place, measurement of the time of day when it occurred is usually superfluous. This results from the narrowness of the central zone on the Earth's surface. The effect of increasing ΔT is to displace the whole of the calculated zone of totality or annularity towards more easterly longitudes, the converse being true if ΔT is diminished. For any particular observation, made at a site with latitude ϕ deg and longitude Λ deg, an *approximate* solution for ΔT may be obtained in the following way. (NB the adopted sign conventions are: positive for latitudes north of the equator and positive for longitudes west of the Greenwich meridian up to 180 deg.)

On the assumption that the Earth has always rotated at its present rate (i.e. $\Delta T = 0$ at any epoch), the longitude Λ' at which the central line intersects the parallel of latitude (ϕ) passing through the site is first derived. The required value for ΔT is then given by the formula

$$\Delta T = 240(\Lambda' - \Lambda) \text{ sec.} \tag{3.4}$$

To give an example of this method of investigation, two separate late Babylonian texts – which are now in the British Museum – describe a complete eclipse of the Sun on a date corresponding to BC 136 Apr 15. (Photographs of both tablets are shown in figures 3.9a and 3.9b.) During totality, four planets and several stars were said to be visible (for full details see chapter 5). This is by far the most reliable ancient record of such a phenomenon.

The zone of totality in 136 BC – computed on the assumption that $\Delta T = 0$ – is shown in figure 3.10a. This zone would pass far to the west of Babylon ($\phi = +32.55$ deg, $\Lambda = -44.42$ deg), the central line crossing the parallel of latitude for the city at $\Lambda' = +4.3$ deg. Hence in order to obtain satisfactory agreement with the record, a correction in longitude of approximately +48.8 deg would be required. Such a correction implies a result for ΔT of around +11 700 sec (3.25 h). The computed central line with $\Delta T = +11\,700$ sec is depicted in figure 3.10b.

In practice, it is possible to set *firm* upper and lower bounds to the value of ΔT at the appropriate epoch by taking into account the width of the zone of totality or annularity. Thus, as shown in figure 3.11, for the southern edge of the umbral shadow to just reach Babylon, a value for ΔT of +11 210 sec (3.11 h) would be needed. For the northern edge to reach the site, the corresponding figure would be +12 140 sec (3.37 h). Hence to fully satisfy the observation, only values of ΔT between these two limits – i.e. $+11\,210 < \Delta T < +12\,140$ sec – are acceptable. The true value of ΔT in 136 BC has an equal probability of lying anywhere in this interval, but not outside it; this represents a tolerance of no more than about four per cent relative to the mean figure of +11 680 sec. It should be mentioned here that I have usually estimated ΔT limits obtained from observations of total and annular obscurations – and also for careful reports which specifically deny a central eclipse – to the nearest 10 sec. All other ΔT values or limits (e.g. obtained from contact timings or rising and setting phenomena) will be quoted to the nearest 50 sec – a precision which is still more than adequate for investigating long-term trends in ΔT.

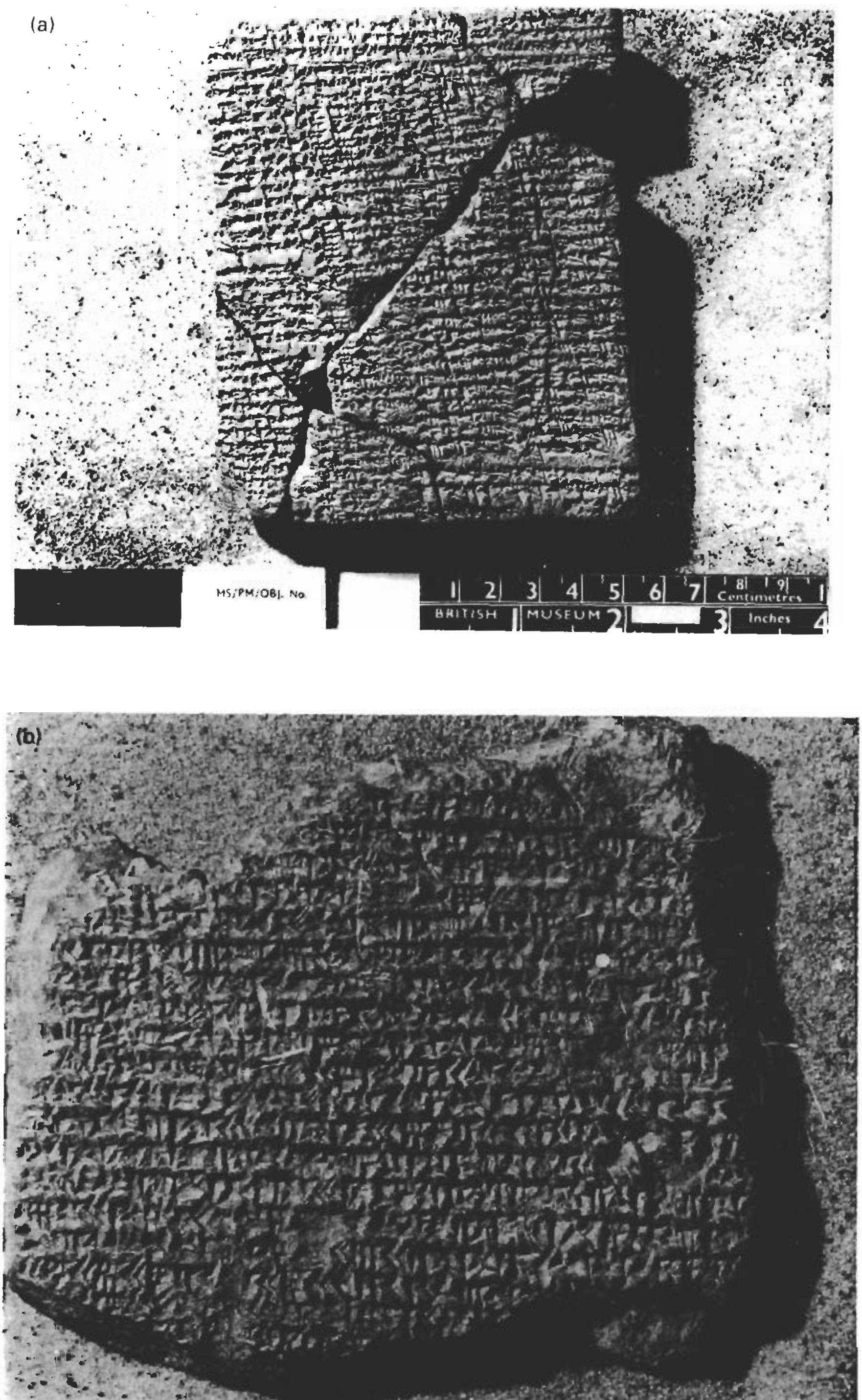

Fig. 3.9 Two Late Babylonian tablets describing a complete eclipse of the Sun on a date corresponding to BC 136 Apr 15. (Courtesy: British Museum.)

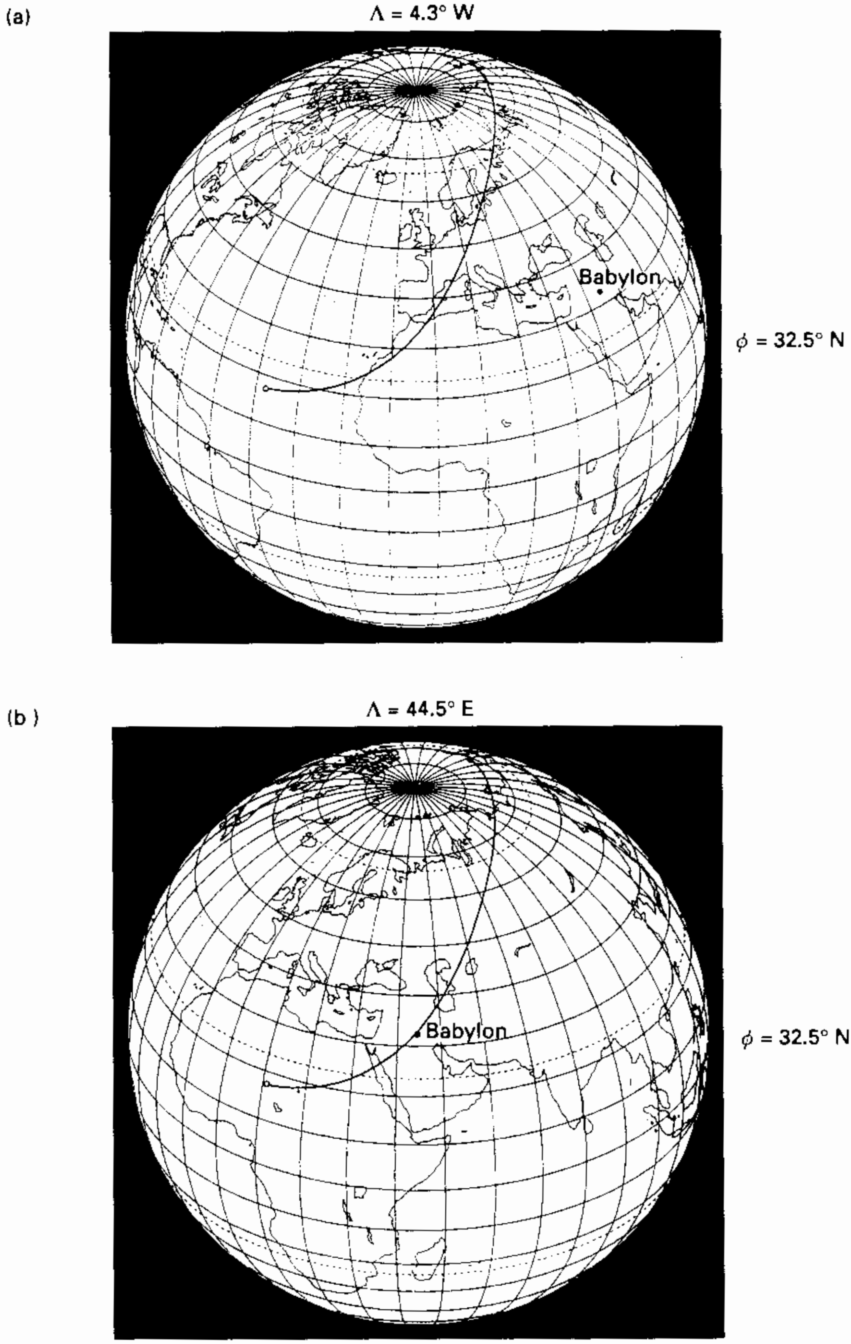

Fig. 3.10 Zone of totality in 136 BC, computed on the assumption that (a) $\Delta T = 0$ and (b) $\Delta T = +11\,700$ sec. The eclipse was observed to be complete at Babylon. (Courtesy: Dr S. Bell.)

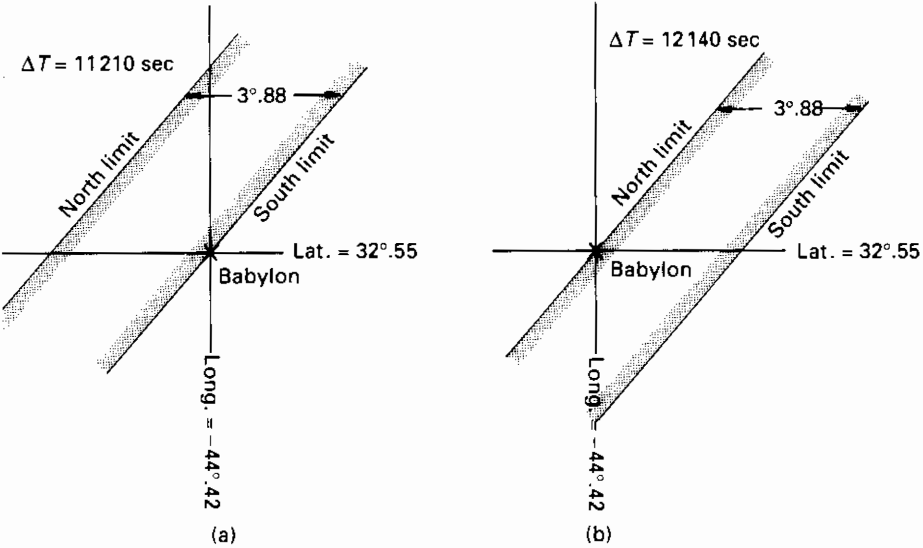

Fig. 3.11 Lower (a) and upper (b) bounds to the value of ΔT as derived from observations of the total solar eclipse of 136 BC at Babylon.