ΔT from solar eclipse on 754 June 25 observed in India and solar eclipse on 761 August 5 observed in China

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Abstract

In this report, we determine the possible narrow range of ΔT at around AD 754. The eclipse on AD 754 June 25 was observed in Pattadakallu, India as total from which we obtain 2900 s $< \Delta T <$ 3430 s. Contemporaneously, the eclipse on AD 761 August 5 was observed at Chang-an as total from which we obtain 1700 s $< \Delta T <$ 3270 s. Two observations compliment each other and make their reliability strong. We obtain the range of ΔT for AD 754 – 761 as 2900 s $< \Delta T <$ 3270 s.

Period	Range of ΔT
754 June 25	2900 s $< \Delta T <$ 3430 s
761 August 5	1700 s $< \Delta T <$ 3270 s

1 Introduction

There are a lot of solar eclipse records inscribed on stones in south India [5, 6]. One of the authors (G.K.G.) went back to the original stone records, and found that some of the records are based on observations. This is similar to our earlier report [10] in which one of the authors (B.S.S.) went back to the original stones. In the earlier report, the range of the period covered was 10th, 11th, and 12th centuries. This time we concentrate ourselves on one solar eclipse on AD 754 June 25.

The phrase in the inscriptions which corresponds to the above date and event goes:

"... Śrāvaṇamāsē Amāvāsyāyām Sarvvagrāsē Sūryyagrahaṇē ..."

where Śrāvaṇa means the name of the lunar month, māsē means month, Amāvāsyāyām means the new moon day, Sarvvagrāsē means 'Covering the total area', implying totality of the eclipse, and Sūryyagrahaṇē means 'solar eclipse'. Thus, the inscriptions clearly tell us that a total solar eclipse occurred on AD 754 June 25.

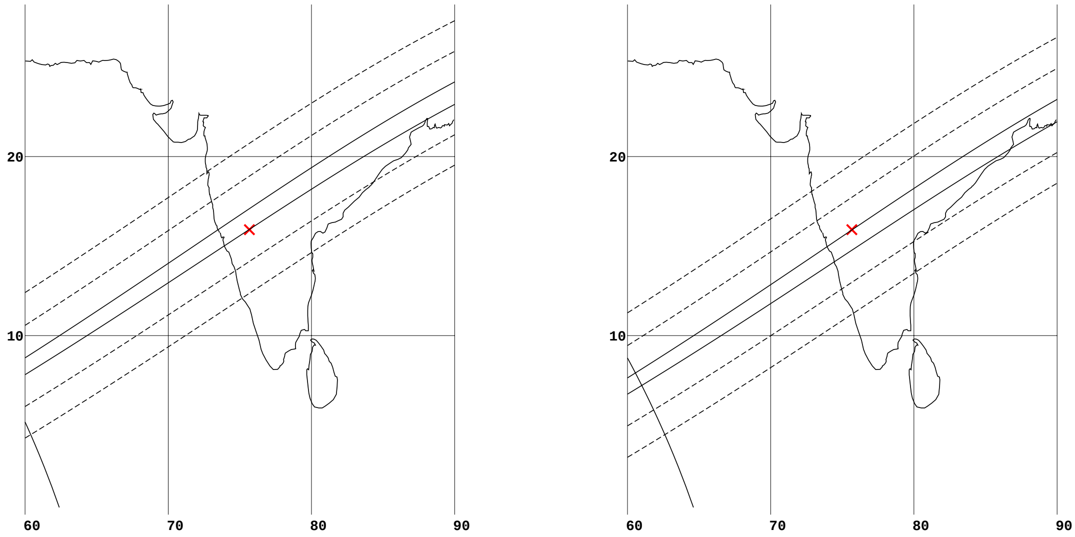

Figure 1: Eclipse bands of the eclipse on AD 754 June 25 for $\Delta T = 2900$ s (left panel), and those for the eclipse on AD 754 June 25 (Right panel) for $\Delta T = 3430$ s. $\times$ denotes Bādāmi Tāluk, Pattadakallu village, Karnataka. The eclipse was total between parallel solid curves. Broken curves are the equi-magnitude curves for magnitude 0.9 and 0.8.

In this section, we first plot the shadow band of the eclipse in Fig. 1 and examine whether the inscriptions are really the reports of observation or predictions.

2 Individual eclipses

2.1 Eclipse on AD 754 June 25

The report of the eclipse on AD 754 June 25 was inscribed on stones in Bādāmi Tāluk, Pattadakallu village, in the premises of Mallikārjuna temple in the present Karnataka state. The longitude and latitude are adopted to be $75^\circ.816$ E and $15^\circ.950$ N. The text is already cited in the Introduction. It is highly probable that observation records were inscribed on the stone. The reason is simple: the predictions in this period had no such accuracy as to say totality.

The record says that the eclipse was total on AD 754 June 25. We plot the band of totality in Fig. 1 for this eclipse. The left panel shows that Bādāmi Tāluk is on the east edge of the totality band, whereas the right panel shows that it is on the west edge of the totality band. Assuming the value of the lunar tidal acceleration be modern (we use this assumption throughout the paper except when we construct the Sôma diagram), the condition that the eclipse was total at Bādāmi Tāluk gives the following range of ΔT on AD 754 June 25:

$$2900 \text{ s} < \Delta T < 3430 \text{ s} \tag{1}$$

This seems a reasonable result.

We have Chinese records of this eclipse. We show the eclipse band covering India and east Asia in Fig. 2. The totality band passes through India in the morning, and South China nearly at noon. The Figure shows that the totality band is on the latitude parallel smaller than 30 degrees. Therefore, we understand that in Chang-an people would not have observed it as a total eclipse.

Chinese records are in Jiu and Xin Tangshu's. In the records below, $\langle\cdot\rangle$ denotes the cyclic number in the sexagenary counting of days (or years). The observation site is Chang-an: 108°.9 N, 34°.3 E. They say

> 天寶十三載六月乙丑朔、日有蝕之、不盡如鈎。 (舊唐書、卷九、玄宗紀下)
> Tian-Bao reign period, thirteenth year, sixth month, yichou $\langle 2\rangle$, first day, solar eclipse, like a hook though not total. (Jiu Tangshu, ninth volume, Emperor Xuanzong, second volume [2])
>
> 天寶十三載六月乙丑朔、(日食)。 (舊唐書、卷三十六、天文下、災異、朔蝕)
> Tian-Bao reign period, thirteenth year, sixth month, yichou $\langle 2\rangle$, first day, (solar eclipse). (Jiu Tangshu, thirty sixth volume, second volume of Tianwen-zhi, disaster chapter, section of solar eclipses [2])
>
> 天寶十三載六月乙丑朔、日有食之。 (新唐書、卷五、玄宗)
> Tian-Bao reign period, thirteenth year, sixth month, yichou $\langle 2\rangle$, first day, solar eclipse. (Xin Tangshu, fifth volume, Emperor Xuanzong [3])
>
> 天寶十三載六月乙丑朔、日有食之、幾既、在東井十九度。京師分也。(新唐書、卷三十二、天文二、日食)
> Tian-Bao reign period, thirteenth year, sixth month, yichou $\langle 2\rangle$, first day, solar eclipse, almost exhausted, the sun was at the 19th degree of constellation Dongjing. The eclipse was partial in the Capital. (Xin Tangshu, thirty second volume, second volume of Tianwen-zhi, solar eclipses [3])

For a reasonable value of ΔT, the magnitude is less than 0.86 at Chang-an as shown in Fig. 3. Descriptions "like a hook" in the Jiu Tangshu, Emperor Xuanzong, and "almost exhausted" in the Xin Tangshu, Tianwen-zhi are a little bit exaggerations. In the other two places of Jiu and Xin Tang-shu's, the eclipse was suggested to be partial. Thus, we do not try to obtain restrictions to the range of the values of ΔT from these Chinese records.

2.2 Contemporaneous eclipse on AD 761 August 5

The eclipse on AD 761 August 5 was observed in Tang Dynasty, China, and recorded in the Jiu and Xin Tangshu's. The observation site is Chang-an.

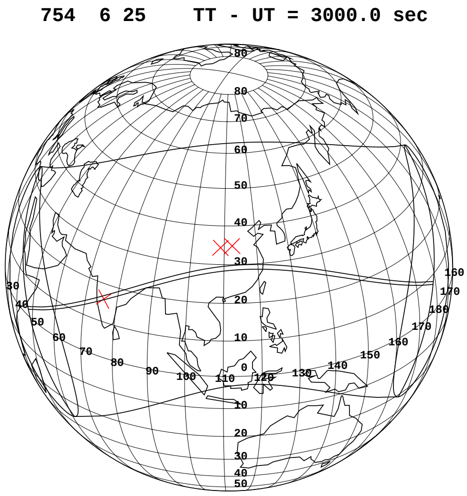

Figure 2: Eclipse band of the eclipse on AD 754 June 25. $\Delta T = 3000$ s. Bādāmi Tāluk, Chang-an, and Luoyang are denoted by $\times$'s. The eclipse was total between narrow parallel solid curves.

上元二年七月癸未朔、日有蝕之、大星皆見。司天秋官正瞿曇奏曰：「癸未太陽虧、辰正後六刻起虧、巳正後一刻既、午前一刻復滿。虧於張四度、周之分野。」(舊唐書、巻三十六、天文下、災異、災異編年、至後)
Shang-Yuan reign period, second year, seventh month, Guiwei $\langle 20 \rangle$, first day, eclipse, all bright stars could be seen. The royal astronomer reported to the Emperor that on Guiwei the sun was eclipsed. The eclipse started after 6 Ku of middle Chen, it was deepest after 1 Ku of middle Si, it ended 1 Ku before Wu. The eclipse occurred at the fourth degree of constellation Zhang, the region of Zhou. (Jiu Tangshu, thirty sixth volume, second volume of Tianwen-zhi, disaster chapter, disaster chronicle after Zhide reign period [2])

上元二年秋七月癸未朔、日有食之、既、大星皆見 (舊唐書、粛宗)
Shang-Yuan reign period, second year, autumn, seventh month, Guiwei $\langle 20 \rangle$, first day, solar eclipse, total, all bright stars could be seen. (Jiu Tangshu, Emperor Suzong [2])

上元二年七月癸未朔、蝕既、大星皆見 (舊唐書、巻三十六、天文下、災異、朔蝕)
Shang-Yuan reign period, second year, seventh month, Guiwei $\langle 20 \rangle$, first day, total eclipse, all bright stars could be seen. (Jiu Tangshu, thirty sixth volume, second volume of Tianwen-zhi, disaster chapter, solar eclipses [2])

上元二年七月癸未朔、日有食之 (新唐書、巻六、粛宗)
Shang-Yuan reign period, second year, seventh month, Guiwei $\langle 20 \rangle$, first day, eclipse. (Xin Tangshu, sixth volume, Emperor Suzong [3])

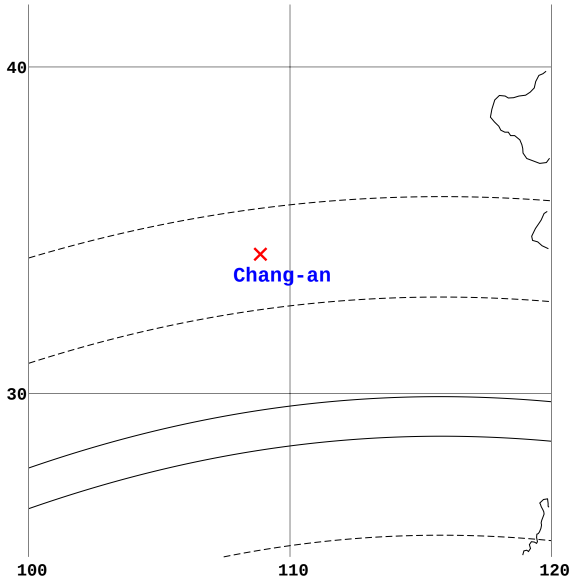

Figure 3: Eclipse bands of the eclipse on AD 754 June 25. This was a partial eclipse at Chang-an. $\Delta T = 2900$. The eclipse was total within the narrow curved parallels (solid). The broken curves are the equi-magnitude curves. Two of them closer to the totality are for magnitude 0.9. The remaining one is for magnitude 0.8.

> 上元二年七月癸未朔、日有食之、既、大星皆見、在張四度。 (新唐書、卷三十二、天文二、日食 [3])
> Shang-Yuan reign period, second year, seventh month, Guiwei ⟨20⟩, first day, solar eclipse, total, all bright stars could be seen, in the fourth degree of constellation Zhang. (Xin Tangshu, thirty second volume, second volume of Tianwen-zhi, solar eclipses [3])

Except the dispassionate description of Emperor's chronicle in Xin Tangshu, descriptions in the other parts of Xin and Jiu Tangshu's of the eclipse are strong and contain 'all bright stars could be seen'. In addition, the descriptions are most talkative compared with those for the other deep eclipses either almost total or total observed in Chang-an in the 8th century: 702 Sep. 26, 729 Oct. 27, 754 June 25, and 756 Oct. 28. We are inclined to take the eclipse as total though the phrase was sometimes used when the eclipse was almost total. Then, we obtain the range of the value of ΔT (Fig. 4) as

$$1700 \text{ s} < \Delta T < 3270 \text{ s} \tag{2}$$

In Japan, there is a record of this eclipse in the Shoku-Nihongi [1]. We do not use this record because we know that the records of solar eclipses in the Nara period (710 - 794 AD) were predicted [8].

2.3 Combined ΔT: Sôma Diagram

Now, we have two independent observations of solar eclipses, one on AD 754 June 25 and the other on AD 754 August 5 both total at each site. Let us plot the Sôma diagram in which the abscissa stands for the correction to the tidal coefficient of the

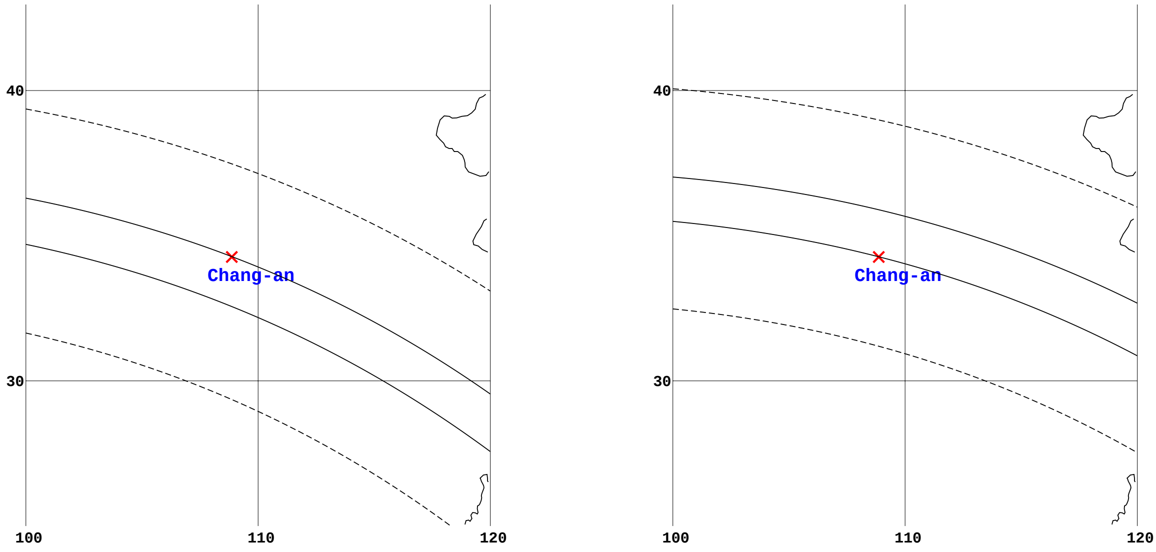

Figure 4: Eclipse bands of the eclipse on AD 761 August 5. $\Delta T = 1700$ s in the left panel, while $\Delta T = 3270$ s in the right panel. Chang-an is denoted by $\times$. The eclipse was total within the narrow curved parallels (solid). The broken curves are for equi-magnitude 0.9.

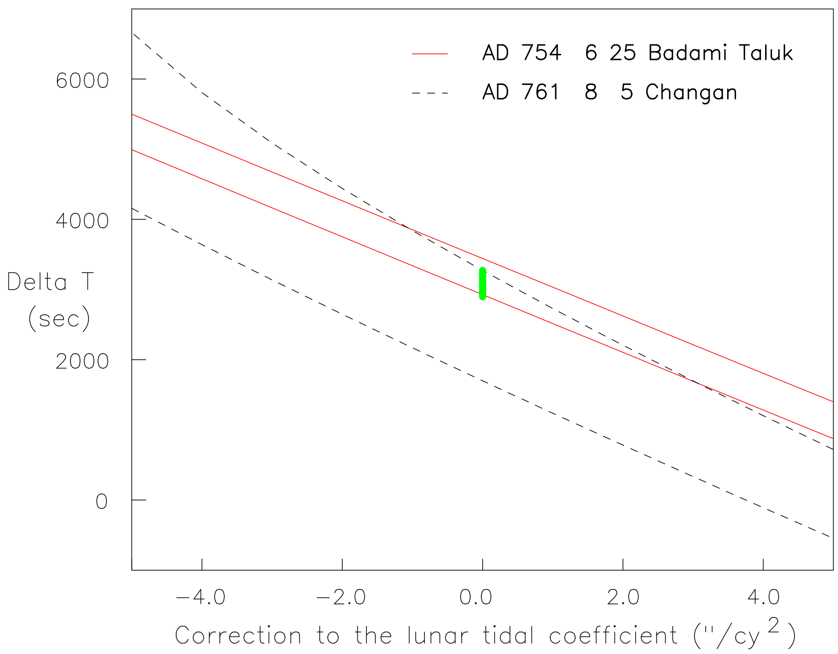

Figure 5: ΔT obtained by combining the records of the eclipse on AD 754 June 25 and the eclipse on AD 761 August 5.

lunar motion, and the ordinate stands for ΔT. Zero in the abscissa corresponds to the modern value of the lunar tidal coefficient. In Fig. 5, the region sandwiched by the red two parallels represents the parameter area where the eclipse on AD 754 June 25 was total at Bādāmi Tāluk, Karnataka, India, whereas the region sandwiched by the broken parallels represents the parameter area where the eclipse on AD 761 August 5 was total at Chang-an, China. Restricting the correction to the lunar tidal coefficient to the modern value, we obtain the range of ΔT as shown in the green vertical bar. We obtain as a common interval,

$$2900 \text{ s} < \Delta T < 3270 \text{ s} \tag{3}$$

3 Summary: Long-term trend of ΔT

We have been adding the individual ΔT one by one to the graph of long-term variations of ΔT (Tanikawa & Sôma [7]; Tanikawa, Yamamoto, & Sôma [11]; Sôma & Tanikawa [4]; Tanikawa, Sôma, & Ueda [9]). We show in Fig. 6 the data of the present report added to the formerly obtained ones. As we know, the climate is warming if the ΔT curve is flat or rising to the right, while the climate is cooling if the slope to the right is steep compared with the average variations. The present result suggests that during AD 754 and 873, the climate is warming suggesting that the climate is warmest at around AD 873.

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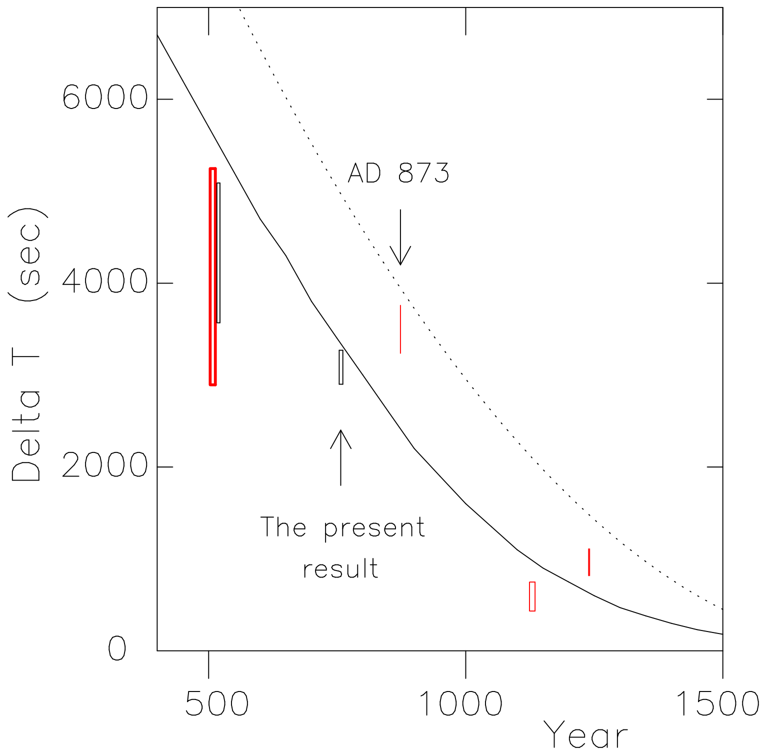

Figure 6: Long-term variations of ΔT between AD 500 and AD 1300. The red and black boxes around AD 500 are obtained from Chinese occultations and solar eclipses [4]. The vertical bar at 873 AD is obtained from observations of a single solar eclipse at Nishapur (Iran) and Kyoto (Japan) [7]. The red box around AD 1130 is obtained from many European solar eclipses [9]. The bar at around AD 1240 is obtained from Korean, Egyptian, and European eclipses [9]. The ranges of ΔT are 2893 s $< \Delta T <$ 5246 s for AD 503 – 513, 3568 s $< \Delta T <$ 5090 s for AD 516 – 523, 3237 s $< \Delta T <$ 3760 s for AD 873, 433 s $< \Delta T <$ 748 s for AD 1124 – 1135, and 817 s $< \Delta T <$ 1110 s for AD 1239 – 1241.

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