ΔT from solar eclipses around 1415 AD

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Abstract. We look for the values of ΔT at around 1415 AD. There are eclipses on 1406 June, 16 and 1415 June 7 which were observed in many cities. In particular, the latter was observed both in Japan and in Europe. The supposed arrival of the Māori at Aotearoa (New Zealand) was in 1408 AD. The adventurers of Māori watched the total or almost total eclipse when they explored the central valcanic plateau of the North Island of Aotearoa. This eclipse was that on 1409 Oct. 9. Our study shows that the range of ΔT is $168\ \mathrm{s} < \Delta T < 675\ \mathrm{s}$. ΔT of the neighboring years are $738\ \mathrm{s} < \Delta T < 830\ \mathrm{s}$ for 1390-1397 and $540\ \mathrm{s} < \Delta T < 679\ \mathrm{s}$ for 1431-1433. So the value of ΔT for 1409 AD may be larger than $500\ \mathrm{s}$. Adopting this value, we obtain that lake Taupō belonged to the area of total eclipse. This exactly correspnds to what the Māori traditions tell.

1 Introduction

We have been interested in the short term variations in the long term trend of ΔT through our history, where $\Delta T = \mathrm{TT} - \mathrm{UT}$ expresses the retardation of the Universal Time (UT) measured by the rotation of the Earth compared with the Terrestrial Time (TT) which is supposed to flow uniform. We know that the spin rate of the earth decreases steadily. This is confirmed directly in a short timescale by the Lunar laser ranging started in 1969 (Chapront et al. 2002), and is confirmed in a long timescale by using the ancient lunar and solar eclipses and occultations of stars by the Moon (Tanikawa & Sôma 2004; Stephenson, 1997).

In the present report, our purpose is to obtain narrow ranges of ΔT at around the beginning of the fifteenth century. We have good records of deep solar eclipses in Asia and in Europe.

2 Solar eclipses and ΔT

2.1 ΔT from eclipses of years 1361, and 1366

2.1.1 Eclipse on 1361 May 5

At Shanghai (total)

日将没、忽無光、作蕉叶様、天黒如夜、星斗燦然、食頃、天再明、又少時乃没。(上海『松江府志』)

(Translation)
Before the sunset, suddenly the light went away, as covered by plantain leaves, the sky became dark like a night, stars shone bright, after a mealtime, the sky became bright again, and then in a short time the sun set. (*Sh'anghǎi* "Sōngjiāngfǔ-zhì")

We judge that the eclipse was total at Sōngjiāngfǔ (松江府), Sh'anghǎi. We plot the shadow band of the eclipse in Fig.1 with $\Delta T = 1000$ s. We get the range of ΔT so that the eclipse was total at Sōngjiāngfǔ as

$$530\ \mathrm{sec} < \Delta T < 1800\ \mathrm{sec}.$$

2.1.2 Eclipse on 1366 Aug. 7

Kaesong

恭愍王十五年七月辛巳朔, 日食既 (高麗史)

(Translation)
King Gonggong reign period, fifteenth year, seventh month, Sinhwa [18], Pus, total solar eclise (*Goryeo-sa*)

Name	Langitude	Latitude	
Perugia	12°23′	43° 7′	
Neider Alteich	12°42′	48°52′	
Braunschweig	10°30′	52°15′	
Hamburg	10° 0′	53°33′	
Prague	14°25′	50° 6′	
Foligno	12°43′	42°57′	
Celle	10° 4′	52°38′	
Nurnberg	11° 5′	49°27′	
Karlstejn	14°12′	49°57′	
Kaesong	126°34′	37°58′	
Hanseongbu	126°59′	37°35′	Seoul
Nanjing	118°47′	32° 2′	(1368 - 1421)Jianye
Shanghai	121°14′	31° 2′	(松江府)
Kyoto	135°48′	35° 0′	
Aizu	139°56′	37°29′	
会津坂下町塔寺	139°48′	37°34′	福島県 河沼郡

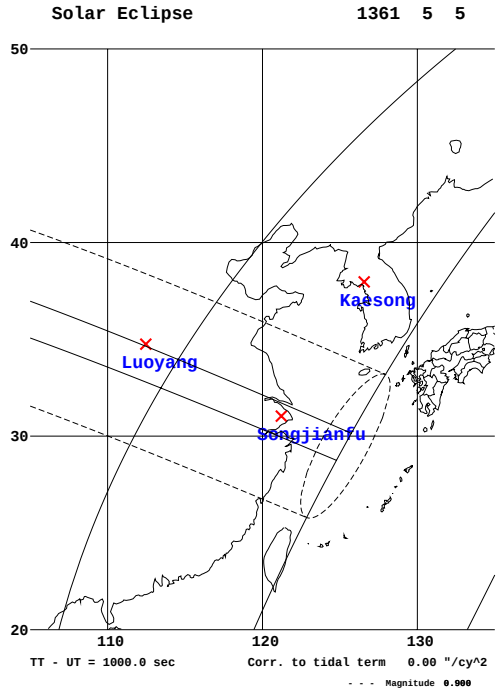

Fig. 1. The shadow of eclipse on 1361 May 5.

For Kaesong, totality is realized for

$$-890\ \mathrm{s} < \Delta T < -810\ \mathrm{s}.$$

The magnitude is 0.95 if $\Delta T = 300$ s, and 0.90 if $\Delta T = 1380$ s. As for the observations in Kyoto, we obtain $\Delta T > 50$ s so that Kyoto is out of the totality band. We obtain $\Delta T > 300$ s

2.1.3 ΔT

Eclipse in 1366 does not give us good information for the range of ΔT. Thus two eclipses in 1361 and 1366 give us the range of ΔT as

$$530\ \mathrm{sec} < \Delta T < 1800\ \mathrm{sec}.$$

which is given only by the eclipse in 1361. We can say that the other eclipse give us information consistent with this range.

2.2 ΔT from eclipses of 1385 Dec. 31, 1390 Oct. 9, and 1397 May 26

2.2.1 Eclipse on 1385 Dec. 31

All the records quoted in Ginzel(1884) say that the eclipse was deep, but not total. Our calculation for a reasonable value of ΔT shows that the magnitude at Perugia and Milano was larger than 0.99. However, the totality band is nearly parallel to the latitude lines. We cannot get a good restriction to the values of ΔT.

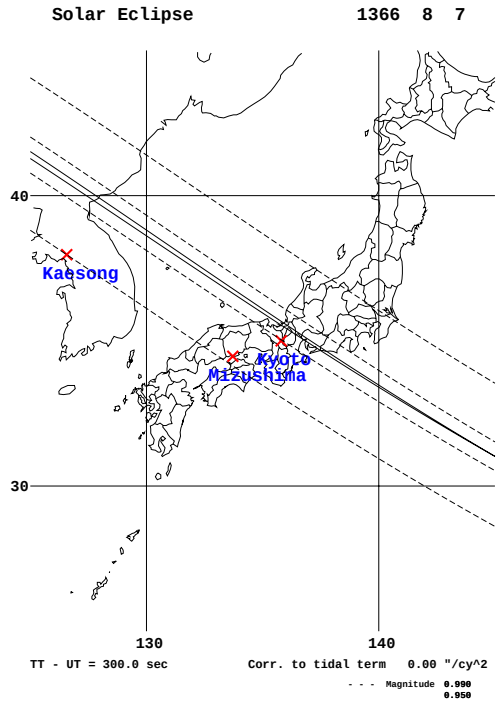

Fig. 2. The shadow band of the eclipse on 1366 Aug. 7 in Korea and Japan. Dashed curves are equi-magnitude ones. Kyoto was on 0.99 and Kaesong was 0.95 for $\Delta T = 300$ s.

2.2.2 Eclipse on 1390 Oct. 9

At Kaesong

恭讓王二年九月庚寅朔, 日食既 (高麗史)

(Translation)
King Gongsu reign period, second year, ninth month, Gengin [27], Pus, a total eclipse (*Goryeo-sa*)

For Kaesong,

$$738\ \mathrm{s} < \Delta T < 830\ \mathrm{s}.$$

2.2.3 Eclipse on 1397 May 26

at Hanseongbu (Seoul)

太祖六年五月壬子朔, 日有食之既 (朝鮮王朝実録)

(Translation)
Taijeu reign period, sixth year, fifth month, Renja [49], there was an eclipse, total. (*Sillok*)

For Hanseongbu (Seoul),

$$266\ \mathrm{s} < \Delta T < 1619\ \mathrm{s}.$$

2.2.4 ΔT

The record of 1390 Oct. 9 may be not reliable because the Goryeo Dynasty perished in 1392. However, Goryeo and Choseon Dynasties are almost continuously connected, so the astronomers might have been not so much affected by outside political and military disturbances.

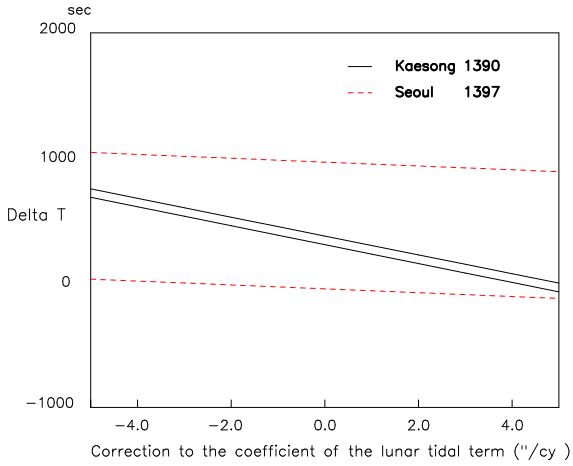

Fig. 3. eclipses of 1390 Oct. 9 at Kaesong, 1397 May 26 at Seoul.

2.3 ΔT from eclipses of years 1406, 1413, and 1415

2.3.1 Asian observations of eclipse on 1406 June 16

All the records in China, Korea, and Japan say the eclipse was partial. These are Ming-shi (明史)、(Ming, Huìyào (明会要)、Èrshēnyělù (二申野録) for China, Choseon wangjo Shillok (朝鮮王朝実録) for Korea, and Zoku-Honchou-Tsugan (続本朝通鑑), Zoku-Shigu-Shou (続史愚抄), and Noritokikyo-ki (教言卿記) for Japan. Our calculation shows that the east Asian sities were deeply in the partial eclipse band. So we cannot get stringent restrictions to the range of ΔT value.

2.3.2 European observations of eclipse on 1406 June 16

The Eouropean record of Braunschweig says that the eclipse was total, and the record of Hirschau suggests that it may be deep but non-total. According to Stephenson(1997), the eclipse was total in Hamburg. This gives $-838\ \mathrm{s} < \Delta T < 736$ s. The totality in Braunschweig gives us $168\ \mathrm{s} < \Delta T < 1698$ s. The partiality of the eclipse in Hirschau gives us $\Delta T < 1350$ s. We obtain the final range of ΔT as a common range

$$168\ \mathrm{s} < \Delta T < 736\ \mathrm{s}$$

from the data of Hamburg, Braunschweig, and Hirschau.

2.3.3 Japanese observations of eclipse on 1413 Feb. 1

At Kyoto

正月一日辛巳、朝程天陰、已後小雪時々降、但陰晴不定、未初刻ヨリ天晴、蝕始、申半刻加持、酉半刻複末。(満濟准后日記)

(Translation)
First month, first day Kanoto-mi [18]. In the morning, it was cloudy, and every now and then light snow after that, and the weather was not stable. From the first thirty minutes of Hitsuji-sho koku, the sky became clear and, (according to the prediction) the eclipse started, magnitude is deepest at the middle of Saru Koku, and the eclipse ends at the middle of Tori koku. (*Diaries of monk Mansai Jugou*)

春正月朔、日有食之既、薩戒記、文正年代記 (倭史後篇二)

Spring, First month, Saku, there was a total solar eclipse. *Satsukai Diary, Bunshou Chronicles (The Latter volume Two of the History of Wa)*

This eclipse has been recorded in thirteen literatures. Most literatures do not say 'total'. Only *Satsukai Diary* and *Bunshou Chronicles* say that the eclipse was total. We judge the eclipse was deep but not total. Assuming Kyoto as the observation site,

$$\Delta T < 950\ \mathrm{s}$$

2.3.4 Japanese observations of eclipse on 1415 June 7

At Aizu

(鏖永十二年) 五月朔日、如夜闇、半時許。(曾津四家合考)

(Translation)
(Ouei reign period, twelfth year) fifth month, Saku, for about one hour, it was dark like a night. (*Aizu Sike Goukou*: History of Four Families of Aizu)

(鏖永十二年) 五月朔日、酉刻如闇、半時許。(曾津土宜考)

(Translation)
(Ouei reign period twelfth year) fifth month, Saku, for about one hour in Tori Koku, it was dark. (*Aizu Dogikou*: Study of Aizu' Products)

(福島県 河沼郡会津坂下町塔寺)
(鏖永十二年) 五月一日、酉刻許一天下入黒闇、半時許也。(塔寺長帳)

(Translation)
(Ouei reign period twelfth year) fifth month, first day, around Tori Koku, the world became in darkness for nearly one hour. (*Toudera Nagachou*, Fukushima Prefecture, Kawanuma County, Aizu-Sakashita, Toudera)

The above three records say that the eclipse was total in Aizu. The records were written nearly two hundred years before the Tokugawa Shogunate established the government in 1600.

Kyoto

(鏖永十二年) 五月丁酉朔、日食。(続本朝通鑑)

(Translation)
(Ouei reign period twelfth year) fifth month, Hinoto-tori [34], Saku, eclipse. (*Zoku-Honchou-Tsugan*)

The totality in Aizu gives us

$$50\ \mathrm{s} < \Delta T < 1400\ \mathrm{s}$$

The record says the eclipse was partial in Kyoto. The above range satisfies the partiality condition of the eclipse in Kyoto.

2.3.5 European observations of eclipse on 1415 June 7

Neider Alteich

1415. Facta est eclipsis solis tenebrosa, itaquod sol omnino emisit lumen suum quasi ad duo Miserere-mei, hora sexta diei, septima die mensis Junii, (*Notae Altahense*) quoted in Ginzel (1884).

(Translation)
1415. A dark eclipse of the Sun occurred with the result that **the Sun entirely lost its light** for twice the duration of the *Misere-mei*(Psalm 51) at the 6th hour of the day on the 7th day of June.
(*Notae Altahenses*; MGH, XVII, 424.)

The meaning of "for twice the duration of the Meisere-mei" is unclear.

Prague

1415. Item septima die menses Junii, quae erat feria VI. post Bonifacii hora XI. eclipsatus est totus sol, itaquod non poterant misse sine luminibus celebravi. In signum quod sol iustitie Christus in cordibus Prelatorum multorum ad mortem magistri Johannis Hus de proximo per Concilium mortificandi anlielantium, fuit obscuratus. (*Magister Laurentiusde Brezina. De gestis et variis accidentibus regni Boemiae.* quoted in Ginzel(1884))

(Translation)
1415. At the same time, on the 7th day of June, which was the sixth day of the week, after the Feast of S. Boniface (jun 5), at the 11th hour of the day, **the whole Sun was eclipsed.** As a result, the Mass could not be celebrated without lights... (This happened) on account of the death of Master Jan Hus (which occurred) soon afterwards...
(Magister Laurentius de Brezina. *De gestis et variis accidentibus regno Boemiae*).

The description "the Mass could not be celebrated without lights" suggests that the eclipse was total at Prague.

Krakau

1415. Anno quo supra feria sexta post Corporis Christi, hora tertiarum, adeo notabilis eclipsis solis fuit, ut alites subita caligine deterrite, in terram deciderent. Et sidera non secus,. quam nocte collucerent. (*Math, de Michova Chron. Polonorum, lib. IV c. LI.* quoted in Ginzel(1884))

(Translation)
1415 Year on the Friday after Corpus Christi (= oct. 6) at the third hour of the day, a notable eclipse of the Sun appeared. As a result of this unexpected and unfamiliar event, such a degree that to be birds, terrified by the sudden darkness, fell to the ground, and the stars were shining as if by night.

The above sentences contain real observations of the surroundings such as "birds, terrified by the sudden darkness,", "the stars were shining as if by night".

2.3.6 ΔT

For Aizu, $39\ \mathrm{s} < \Delta T < 1410\ \mathrm{s}$, for Touji, $45\ \mathrm{s} < \Delta T < 1417\ \mathrm{s}$, for Nieder Alteich, $-796\ \mathrm{s} < \Delta T < 955\ \mathrm{s}$, and For Prague, $-1164\ \mathrm{s} < \Delta T < 675\ \mathrm{s}$.

We obtain

$$45\ \mathrm{s} < \Delta T < 675\ \mathrm{s}$$

from the data of Aizu, Touji, Nieder Alteich, and Prague.

From eclipses on 1406 June 16 and 1415 June 7, the range of ΔT is obtained as

$$168\ \mathrm{s} < \Delta T < 675\ \mathrm{s}$$

2.4 ΔT from eclipse on 1420 Sept. 8

Eclipse on 1420 Sept. 8 has records in Ming-Shi. The description is simple:

明成祖永楽十八年八月丁酉朔、日有食之。(明史、成祖三)

(Translation)
Emperor Cheng, Yongle reign period, 18th year, eighth month, dīngyǒu [34], the first day, there was an eclipse. (*Ming-shi, Emperor Cheng, third volume*)

Our preliminary calculation shows that the

eclipse was very deep at Nanjing. Strangely, The Ming-shi states quietly the fact that there was an eclipse. More strange is that the *Ming-shi* does not systematically compile the records of eclipses. Anyway we plot the eclipse bands of the eclipse in Fig. **??**. We obtain either $\Delta T > 500$ s or $\Delta T < 300$ s in order that the eclipse was not total at Nanjing.

2.5 ΔT from eclipses of years 1431 and 1433

2.5.1 Two European observations of eclipse on 1431 Feb. 12

For perugia, $-188\,\mathrm{s} < \Delta T < 679$ sec For Foligno, $-16\,\mathrm{s} < \Delta T < 846$ sec

We have

$$-16\,\mathrm{s} < \Delta T < 679\ \mathrm{sec}$$

from the condition that the eclipse was total both at perugia and Foligno.

2.5.2 Three observations of eclipse on 1433 June 17

The record says the totality of the eclipse. However, we postpone the conclusion until we draw the Sôma diagram.

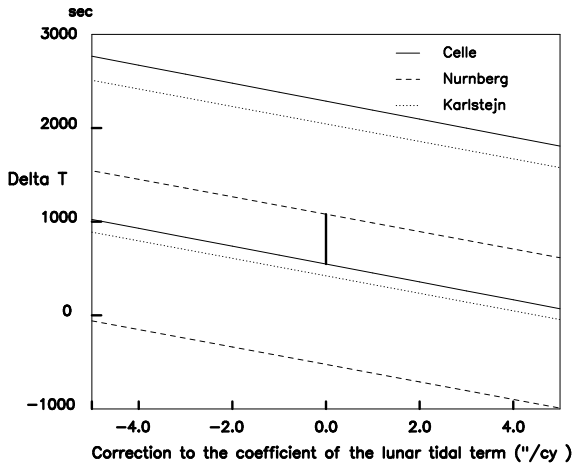

Fig. 4. eclipses of 1433 June 17 at Celle, Nurnberg, and Karlstejn.

2.5.3 ΔT

For Celle, $548\,\mathrm{s} < \Delta T < 2287$ sec, for Nurnberg, $-524\ \mathrm{s} < \Delta T < 1080$ sec, and for Karlstejn, $-422\,\mathrm{s} < \Delta T < 2044$ sec. We have

$$548\,\mathrm{s} < \Delta T < 1080\ \mathrm{sec}$$

from the condition that the eclipse was total at Celle, Nurnberg, and Karlstejn.

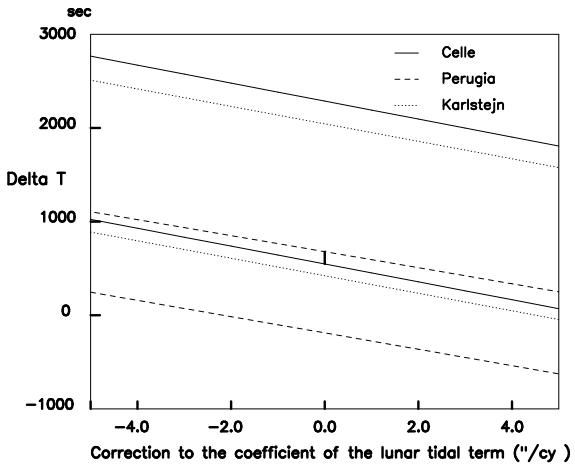

Fig. 5. eclipses of 1431 Feb. 12 at Foligno and Perugia, and 1433 June 17 at Celle, Nurnberg and Karlstejn. We do not plot the data of Nurnberg and Foligno because they are redundent.

Together with the data on 1431 Feb. 12, we have a narrow range

$$548\,\mathrm{s} < \Delta T < 679\ \mathrm{sec}$$

for the period includin 1431 and 1433.

3 Variations of ΔT around year 1415

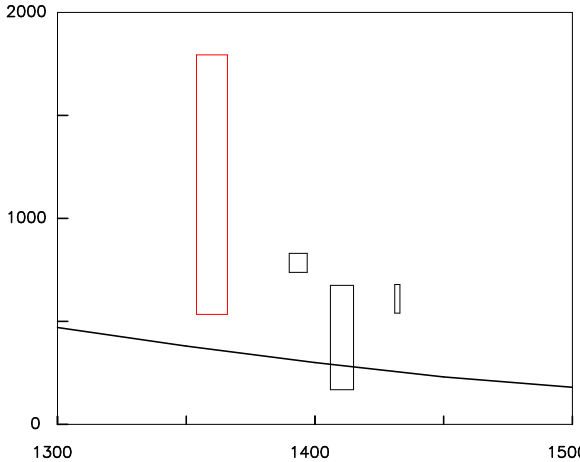

Fig. 6. Variations of ΔT during AD 1350 and 1450. $534\,\mathrm{s} < \Delta T < 1794$ s for 1354 and 1366, $738\,\mathrm{s} < \Delta T < 830$ s for 1390 and 1397, $168\,\mathrm{s} < \Delta T < 675$ s for 1406 and 1415, $540\,\mathrm{s} < \Delta T < 679$ s for 1431 and 1433,

4 Magnitudes of eclipses of 15 June 1368, 9 October 1409, 2 January 1424, and 25 March 1438 in North Island of Aotearoa (New Zealand)

4.1 Eclipse on 1368 June 15

We show in Fig. 7 the totality and partiality bands of the eclipse on 1368 June 15 assuming $\Delta T = 600$ s. The totality band runs north-west of Lake Taupo and passes across the north Penninsula. Around Taupo, the magnitude of the eclipse was 0.91 – 0.92. The sky was not dark.

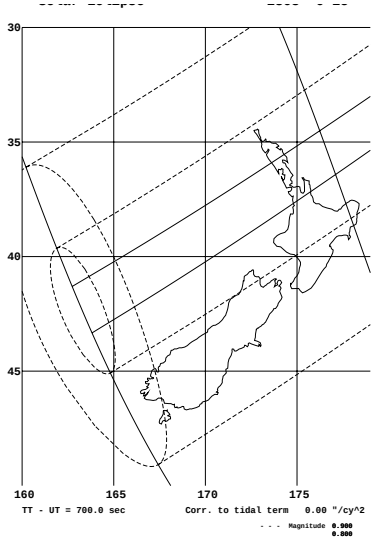

Fig. 7. The shadow band of the eclipse on 1368 June 15 in Aotearoa - New Zealand. Dashed curves are equi-magnitude ones. 0.90, 0.80. $\Delta T = 600$ s.

4.2 Eclipse on 1409 Oct. 9

The totality and partiality bands of the eclipse on 1409 Oct. 9 are shown in Fig. 8. ΔT is set to 600 s. The totality band of the eclipse runs across the North Island from the north-west to the south-east. Lake Taupo is on the north edge of the totality band. So, the sky became dark around Lake Taupo.

4.3 Eclipse on 1424 Jan. 2

We show in Fig. 9 the totality and partiality bands of the eclipse on 1424 Jan. 2 assuming $\Delta T = 600$ s. The totality band was off the north

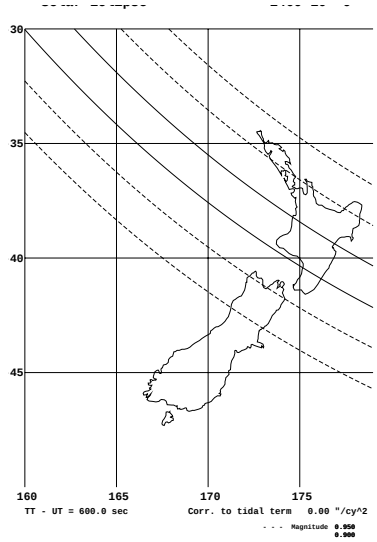

Fig. 8. The shadow band of the eclipse on 1409 Oct. 9 in Aotearoa - New Zealand. Dashed curves are equi-magnitude ones. 0.90, 0.80. $\Delta T = 600$ s.

island. The magnitude of the eclipse was 0.8 around Lake Taupo. So, the sky became not dark.

4.4 Eclipse on 1438 March 25

We show in Fig. 10 the totality and partiality bands of the eclipse on 1438 Mar. 25 assuming $\Delta T = 600$ s. The totality band was grazing the south island and off the north island. The magnitude of the eclipse was 0.85 around Lake Taupo. So, the sky became not dark.

Acknowledgements

The authors are grateful to Mr. Hisashi Hayakawa for information on European literature.

The authors express thanks to Dr. Chijou Udou (kokugakuin University) for the knowledge on Chinese sentences. This work has been partially supported by Grants-in-Aid for Scientific Research (C), 2015 - 2018 (JP15K05038, Mitsuru Soma) "Variations of Earth Rotation and Climates".

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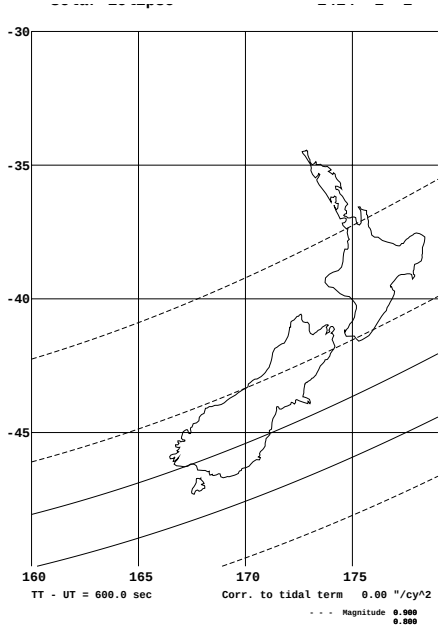

Fig. 9. The shadow band of the eclipse on 1424 Jan. 2 in Aotearoa - New Zealand. Dashed curves are equi-magnitude ones. 0.90, 0.80. $\Delta T = 600$ s.

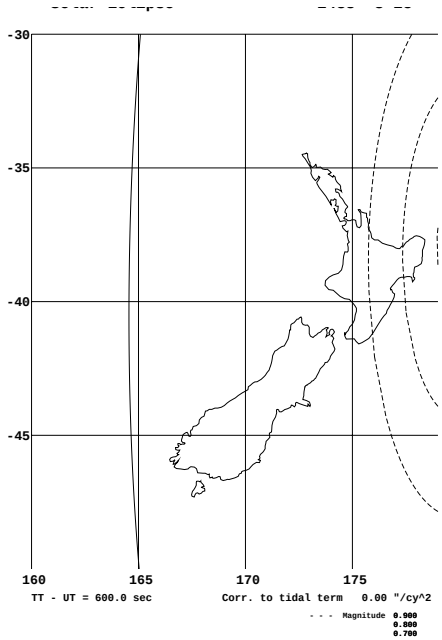

Fig. 10. The shadow band of the eclipse on 1438 March 25 in Aotearoa - New Zealand. Dashed curves are equi-magnitude ones. 0.90, 0.80, 0.70 from the right. $\Delta T = 600$ s.

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