Total Solar Eclipse of -0762 Jun 15

0763BC Jun 15

Fred Espenak

The following table delineates the path of the Moon's umbral shadow during the total solar eclipse of -0762 Jun 15 (0763BC Jun 15). The geographic coordinates of the northern and southern limits are listed, along with the center line. The path characteristics are generated at 2.00° intervals in longitude. This should provide adequate detail for making plots of the path on larger scale maps. Local circumstances on the center line include the Sun's altitude and azimuth, the path width (kilometers) and the duration of the central eclipse.

Eclipse predictions are based on algorithms developed from the *Explanatory Supplement [1974]* and Meeus [1989]. The solar and lunar coordinates were generated from the j=2 ephemerides for the Sun [Newcomb, 1895] and Moon [Brown, 1919, and Eckert, Jones and Clark, 1954]. The value used for the Moon's secular acceleration is n-dot = -26 arc-sec/cy*cy, as deduced by Morrison and Ward [1975]. The value for *delta-T* (delta-T = DT - UT) was determined as follows:

1) pre-1600: delta T was calculated from empirical expressions derived by *Stephenson [1997]*
2) 1600-present: delta T was obtained from published observations
3) future: delta-T was extrapolated based on current values and trends

A correction of -0.6 arc-seconds was added to the Moon's ecliptic latitude to account for the difference between the Moon's center of mass and center of figure. These predictions use a smaller value of k (=0.272281) than the one adopted by the 1982 IAU General Assembly (k=0.2725076). This results in a better approximation of Moon's minimum diameter and a slightly shorter total or longer annular eclipse when compared with calculations using the IAU value for k.

Total Solar Eclipse of -0762 Jun 15 (0763BC Jun 15)

Mapping Coordinates for the Path of Totality

Delta T = 22343.0 s

Longitude	Latitude of: Northern Limit	Latitude of: Southern Limit	Latitude of: Center Line	Circumstances on the Center Line: Universal Time (h m s)	Sun Alt (°)	Sun Az. (°)	Path Width (km)	Central Durat.
010°W	15°11.9'N	13°37.8'N	14°24.5'N	06:13:55	1	67	159	02m14s
008°W	16°05.4'N	14°29.3'N	15°17.0'N	06:14:06	4	67	161	02m18s
006°W	16°59.9'N	15°21.9'N	16°10.6'N	06:14:26	6	68	164	02m23s
004°W	17°55.3'N	16°15.4'N	17°05.0'N	06:14:56	8	68	166	02m27s
002°W	18°51.7'N	17°09.8'N	18°00.4'N	06:15:37	10	69	169	02m32s
000°E	19°48.8'N	18°05.0'N	18°56.6'N	06:16:29	12	70	171	02m37s
002°E	20°46.7'N	19°01.0'N	19°53.5'N	06:17:32	15	71	174	02m42s
004°E	21°45.1'N	19°57.6'N	20°51.0'N	06:18:46	17	71	176	02m47s
006°E	22°43.9'N	20°54.7'N	21°49.0'N	06:20:13	20	72	179	02m52s
008°E	23°43.0'N	21°52.2'N	22°47.2'N	06:21:51	22	73	181	02m58s
010°E	24°42.2'N	22°49.8'N	23°45.7'N	06:23:42	24	75	183	03m04s
012°E	25°41.2'N	23°47.5'N	24°44.0'N	06:25:45	27	76	185	03m10s
014°E	26°40.0'N	24°45.0'N	25°42.1'N	06:28:01	29	77	187	03m16s
016°E	27°38.1'N	25°42.0'N	26°39.8'N	06:30:29	32	78	189	03m22s

018°E	28°35.5'N	26°38.5'N	27°36.8'N	06:33:08	34	80	191	03m29s
020°E	29°31.9'N	27°34.2'N	28°32.8'N	06:35:59	37	82	193	03m35s
022°E	30°26.9'N	28°28.7'N	29°27.6'N	06:39:01	39	83	194	03m42s
024°E	31°20.5'N	29°22.0'N	30°21.0'N	06:42:14	42	85	195	03m48s
026°E	32°12.3'N	30°13.6'N	31°12.7'N	06:45:37	44	88	197	03m55s
028°E	33°02.1'N	31°03.5'N	32°02.6'N	06:49:09	47	90	198	04m01s
030°E	33°49.7'N	31°51.3'N	32°50.3'N	06:52:49	49	92	199	04m07s
032°E	34°34.9'N	32°36.9'N	33°35.7'N	06:56:37	52	95	200	04m14s
034°E	35°17.6'N	33°20.0'N	34°18.7'N	07:00:32	54	98	200	04m19s
036°E	35°57.5'N	34°00.6'N	34°59.0'N	07:04:32	56	101	201	04m25s
038°E	36°34.7'N	34°38.5'N	35°36.5'N	07:08:38	59	105	202	04m30s
040°E	37°09.0'N	35°13.5'N	36°11.1'N	07:12:48	61	109	202	04m35s
042°E	37°40.3'N	35°45.5'N	36°42.8'N	07:17:02	63	113	203	04m40s
044°E	38°08.5'N	36°14.5'N	37°11.4'N	07:21:20	65	118	203	04m44s
046°E	38°33.6'N	36°40.3'N	37°36.9'N	07:25:39	67	124	203	04m48s
048°E	38°55.7'N	37°03.0'N	37°59.3'N	07:30:01	69	130	204	04m51s
050°E	39°14.5'N	37°22.5'N	38°18.5'N	07:34:24	70	137	204	04m54s
052°E	39°30.3'N	37°38.8'N	38°34.5'N	07:38:48	72	145	204	04m56s
054°E	39°42.8'N	37°51.8'N	38°47.3'N	07:43:13	73	153	204	04m58s
056°E	39°52.2'N	38°01.6'N	38°56.9'N	07:47:38	73	163	204	04m59s
058°E	39°58.5'N	38°08.2'N	39°03.3'N	07:52:03	74	173	204	04m59s
060°E	40°01.6'N	38°11.4'N	39°06.5'N	07:56:28	74	183	204	04m59s
062°E	40°01.5'N	38°11.5'N	39°06.5'N	08:00:52	73	193	204	04m59s
064°E	39°58.3'N	38°08.3'N	39°03.3'N	08:05:16	73	203	203	04m58s
066°E	39°52.0'N	38°01.9'N	38°56.9'N	08:09:38	72	211	203	04m56s
068°E	39°42.6'N	37°52.3'N	38°47.4'N	08:13:59	70	219	203	04m54s
070°E	39°30.1'N	37°39.5'N	38°34.7'N	08:18:18	69	226	202	04m51s
072°E	39°14.5'N	37°23.5'N	38°18.9'N	08:22:35	67	233	202	04m48s
074°E	38°55.8'N	37°04.4'N	38°00.1'N	08:26:50	66	238	202	04m44s
076°E	38°34.2'N	36°42.3'N	37°38.1'N	08:31:01	64	243	201	04m40s
078°E	38°09.5'N	36°17.1'N	37°13.2'N	08:35:10	62	248	200	04m35s
080°E	37°41.8'N	35°49.0'N	36°45.3'N	08:39:15	59	252	200	04m30s
082°E	37°11.3'N	35°18.0'N	36°14.5'N	08:43:15	57	256	199	04m25s
084°E	36°37.9'N	34°44.2'N	35°40.9'N	08:47:10	55	259	198	04m20s
086°E	36°01.8'N	34°07.7'N	35°04.6'N	08:51:00	53	262	197	04m14s
088°E	35°23.1'N	33°28.6'N	34°25.7'N	08:54:44	50	265	196	04m08s

090°E	34°41.9'N	32°47.2'N	33°44.4'N	08:58:21	48	268	195	04m02s
092°E	33°58.3'N	32°03.5'N	33°00.7'N	09:01:50	46	270	194	03m55s
094°E	33°12.5'N	31°17.7'N	32°14.9'N	09:05:12	43	272	193	03m49s
096°E	32°24.6'N	30°30.1'N	31°27.1'N	09:08:24	41	274	191	03m43s
098°E	31°34.9'N	29°40.7'N	30°37.6'N	09:11:27	38	276	190	03m36s
100°E	30°43.6'N	28°49.9'N	29°46.5'N	09:14:20	36	278	188	03m30s
102°E	29°50.8'N	27°57.8'N	28°54.1'N	09:17:03	34	280	187	03m23s
104°E	28°56.9'N	27°04.7'N	28°00.5'N	09:19:35	31	281	185	03m17s
106°E	28°01.9'N	26°10.7'N	27°06.0'N	09:21:56	29	283	183	03m11s
108°E	27°06.1'N	25°16.1'N	26°10.8'N	09:24:05	26	284	181	03m05s
110°E	26°09.8'N	24°21.1'N	25°15.1'N	09:26:03	24	285	179	02m59s
112°E	25°13.1'N	23°25.8'N	24°19.1'N	09:27:49	22	286	176	02m53s
114°E	24°16.2'N	22°30.4'N	23°23.0'N	09:29:23	19	287	174	02m48s
116°E	23°19.3'N	21°35.1'N	22°26.9'N	09:30:46	17	288	172	02m42s
118°E	22°22.6'N	20°40.1'N	21°31.0'N	09:31:58	14	289	169	02m37s
120°E	21°26.2'N	19°45.4'N	20°35.4'N	09:32:58	12	290	167	02m32s
122°E	20°30.2'N	18°51.2'N	19°40.3'N	09:33:48	10	291	164	02m28s
124°E	19°34.7'N	17°57.5'N	18°45.8'N	09:34:27	8	292	162	02m23s
126°E	18°39.9'N	17°04.5'N	17°51.9'N	09:34:56	5	292	159	02m19s

Total Solar Eclipse of -0762 Jun 15

Geocentric Conjunction = 07:55:48.2 UT   J.D. = 1442902.830419
Greatest Eclipse = 07:55:18.6 UT   J.D. = 1442902.830077

Eclipse Magnitude = 1.05954   Gamma = 0.27795

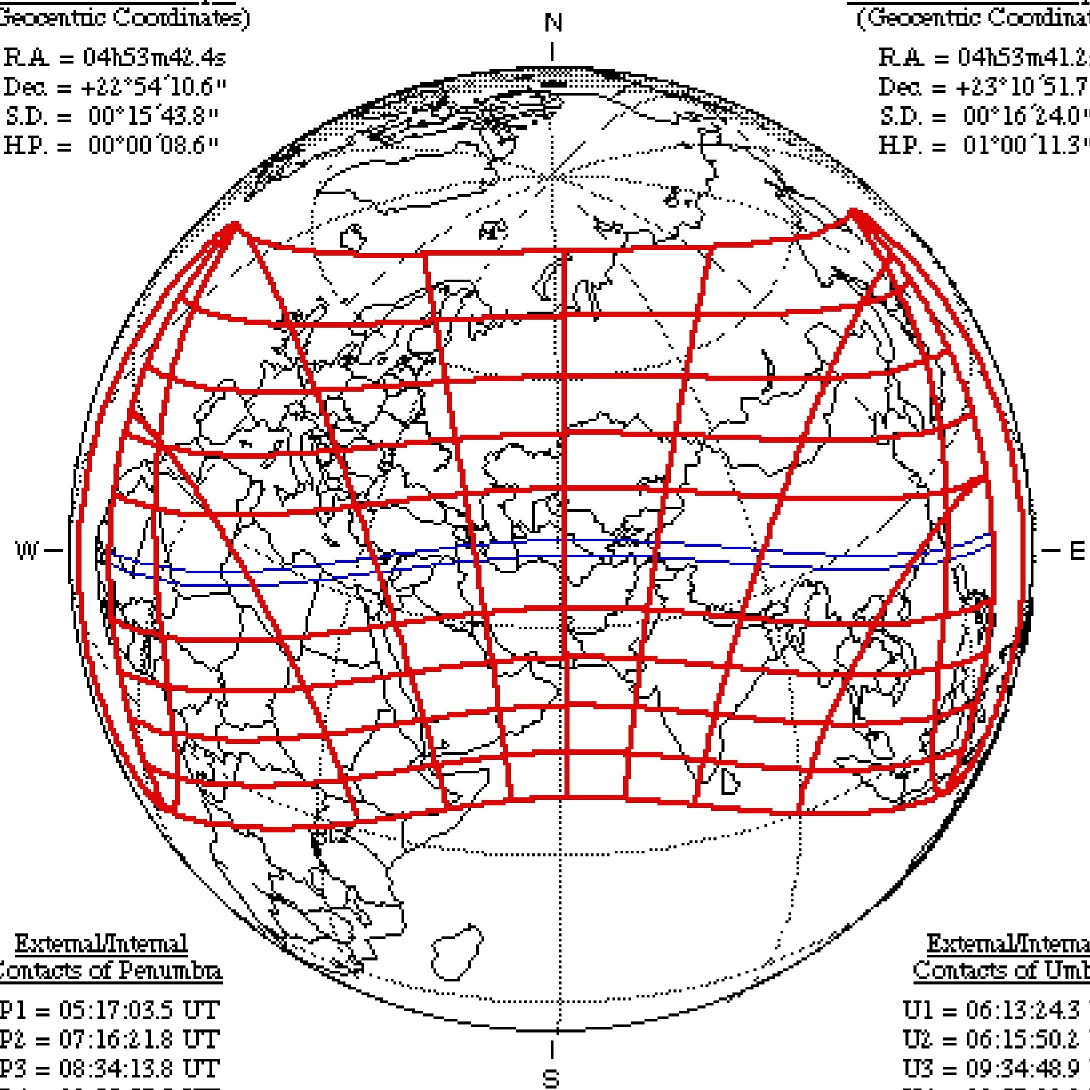
Saros Series = 44   Member = 39 of 72

Sun at Greatest Eclipse
(Geocentric Coordinates)

R.A. = 04h53m42.4s
Dec. = +22°54'10.6"
S.D. = 00°15'43.8"
H.P. = 00°00'08.6"

Moon at Greatest Eclipse
(Geocentric Coordinates)

R.A. = 04h53m41.2s
Dec. = +23°10'51.7"
S.D. = 00°16'24.0"
H.P. = 01°00'11.3"



External/Internal Contacts of Penumbra

P1 = 05:17:03.5 UT
P2 = 07:16:21.8 UT
P3 = 08:34:13.8 UT
P4 = 10:33:37.3 UT

External/Internal Contacts of Umbra

U1 = 06:13:24.3 UT
U2 = 06:15:50.2 UT
U3 = 09:34:48.9 UT
U4 = 09:37:11.0 UT

Local Circumstances at Greatest Eclipse

Lat = 39°14.9'N   Sun Alt = 73.7°
Long. = 058°59.1'E   Sun Azm. = 178.9°
Path Width = 204.0 km   Duration = 04m59.0s

Ephemeris & Constants

Eph. = Newcomb/ILE
ΔT = 19840.3 s
k1 = 0.2724880
k2 = 0.2722810
Δb = 0.0"   Δl = 0.0"

Geocentric Libration
(Optical + Physical)

l = 3.48°
b = -0.33°
c = -8.13°

Brown Lun. No. =32617

F. Espenak, NASA/GSFC - 1997 Jul 29

sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Delta T

In order to calculate for a given place on earth the precise circumstances of an eclipse, it is necessary to know the difference between "Terrestrial Time" (TT), formerly "Ephemeris Time" (ET), and "Universal Time" (UT).

This difference TT - UT = DeltaT.

Especially in the case of solar eclipses a precise knowledge of deltaT is indispensable, since deltaT determines a.o. the times of contact and the magnitude of the eclipse at a given place.

For the calculation of solar eclipses from the 17th century on to the present time precise results can be obtained since for that period deltaT is known sufficiently accurately from telescopic observations.

For investigations on older eclipses things are quite different.

Up till around 1985, deltaT was calculated using the following formula:

(1) deltaT(seconds) = 24.349 + 72.318 T + 29.950 T^2 + small fluctuations
(T = centuries since 1900.0)

This formula was derived from observations since AD 1650 by Spencer JONES (1939) and Gerald M.CLEMENCE (1948), officially accepted by the International Astronomical Union in 1952 en slightly corrected in 1960.

Since 1980 new formulae were proposed a.o. by STEPHENSON & MORRISON (1984) and STEPHENSON & HOULDEN (1986). These were the result of additional research on observations of old solar eclipses in China and the Arab world.

The following formulae were proposed:

(2) period up till AD 948 (STEPHENSON & HOULDEN, 1986)

deltaT(seconds) = 1830 - 405 E + 46. 5 E^2
(E = centuries since 948 AD)

(3) period AD 948 to AD 1600 (STEPHENSON & HOULDEN, 1986)

deltaT(seconds) = 22. 5 t^2
(t = centuries since 1850 AD)

In his recent book "Historical Eclipses and Earth's Rotation" (1997) STEPHENSON presents a new analysis of most if not all known solar and lunar eclipses that occurred during the period -700 to +1600. As a result he presents the following "new" values for deltaT (given here per century):

Table (4)

year	dT(sec)
-500	16800
-400	15300
-300	14000
-200	12800
-100	11600
0	10600
+100	9600
+200	8600
+300	7700
+400	6700
+500	5700
+600	4700
+700	3800
+800	3000
+900	2200
+1000	1600
+1100	1100
+1200	750
+1300	470
+1400	300
+1500	180
+1600	110

If we calculate the value for deltaT using the 3 given formulas and compare the results with those presented by Stephenson

(1997), we obtain the following table for the period -2000 to +1700:

Year	Form (1) **Jones**	Form(2) **St&H(86)**	Form(3) **St&H(86)**	Table(4) **Steph(97)**
-2000	42757	54181	-	-
-1900	40524	51081	-	-
-1800	38350	48073	-	-
-1700	36236	45159	-	-
-1600	34181	42338	-	-
-1500	32187	39610	-	-
-1400	30253	36975	-	-
-1300	28378	34433	-	-
-1200	26564	31984	-	-
-1100	24809	29627	-	-
-1000	23115	27364	-	-
-900	21480	25194	-	-
-800	19905	23117	-	-
-700	18390	21133	-	-
-600	16935	19242	-	-
-500	15539	17444	-	16800
-400	14204	15738	-	15300

-300	12929	14126	-	14000
-200	11713	12607	-	12800
-100	10557	11181	-	11600
0	9462	9848	-	10600
100	8426	8608	-	9600
200	7450	7461	-	8600
300	6534	6406	-	7700
400	5678	5445	-	6700
500	4882	4577	-	5700
600	4145	3802	-	4700
700	3469	3120	-	3800
800	2852	2531	-	3000
900	2296	2035	-	2200
1000	1799	-	1625	1600
1100	1362	-	1265	1100
1200	985	-	950	750
1300	668	-	680	470
1400	411	-	455	300
1500	214	-	275	180
1600	76	-	140	110
1700	-1	-	-	-
1800	-19	-	-	-
1900	24	-	-	-
2000	126	-	-	-

For the period AD 1700 to AD 2000 the observed values are:

+1700	+9 seconds
+1800	+13.7 sec
+1900	-2.7 sec
+2000	+64 sec

It is important to pay attention to the differences in deltaT, depending on the author especially when studying old eclipses, say before AD 1000.
In AD 1500 there is a difference of 95 seconds between the values given by Stephenson & Houlden in 1986 and those by Stephenson in 1997;
In AD 1000 the difference is only 25 seconds between the values given by Stephenson & Houlden and Stephenson, but there is a difference of almost 200 seconds with the Jones' values;
In AD 500 the difference between the Stephensons & Houlden (1986) and Stephenson (1997) values amount to 1123 seconds, while the difference with Jones' values reach 818 seconds;
For the earlier centuries the differences are rapidly increasing to exceed 11400 seconds (this is more than 3 hours !!) around 2000 BC.

When studying ancient eclipses it is important to keep these uncertainties in mind.

Errors of a few minutes will probable hardly affect our ideas of the perception of ancient observers, except perhaps in the case of total or near total solar eclipses that might become near total or total respectively, or in the case of eclipses starting or ending at dawn or sundown.
For the more remote past, when uncertainties in delta T become increasingly important, precise calculations for a given place tend to become very problematic indeed.

Felix Verbelen

Delta T before the Telescopic Era

The most recent and complete analysis of all available observations of solar eclipses, timed lunar eclipses and other data was published by Stephenson & Morrison (1995) and in Stephenson (1997).

Observed values (in seconds) for the period –500 to +1600

Year	Value	Year	Value	Year	Value	Year	Value	Year	Value
–500	+16800	–50	+11100	400	+6700	850	+2600	1300	+470
–450	+16000	0	+10600	450	+6200	900	+2200	1350	+380
–400	+15300	50	+10100	500	+5700	950	+1900	1400	+300
–350	+14600	100	+9600	550	+5200	1000	+1600	1450	+230
–300	+14000	150	+9100	600	+4700	1050	+1350	1500	+180
–250	+13400	200	+8600	650	+4300	1100	+1100	1550	+140
–200	+12800	250	+8200	700	+3800	1150	+900	1600	+110
–150	+12200	300	+7700	750	+3400	1200	+750		
–100	+11600	350	+7200	800	+3000	1250	+600		

In this analysis the tidal acceleration parameter was assumed to be –26.0 arcsec/cy/cy.

An analysis of Stephenson *et al*. (1997) of a solar eclipse observed by Christopher Clavius in Rome in 1567 suggests that the 16th-century values for Delta T may be somewhat higher. This would also remove the apparent jump in Delta T around 1600 when compared with the modern data.

Semi-Empirical Analytical Relations for Delta T before the Telescopic Era

During the past decades several semi-empirical analytical relations have been suggested in the literature as an aid for predicting past and future values for Delta T. When the tidal acceleration parameter is assumed to be constant in time, this results in a parabolic relation for Delta T as function of time (u), or:

$$\text{Delta T} = a + b * u + c * u^2$$

where a, b and c are constants that can be obtained from historical observations of solar and lunar eclipse timings and other data. The origin of *u* is often chosen in such a way that the linear term vanishes (*b* = 0).

IAU (1952)

In September 1952, the eighth General Assembly of the International Astronomical Union in Rome adopted the following formula:

$$\text{Delta T (sec)} = 24.349 + 72.318 * u + 29.950 * u^2 + \text{small fluctuations}$$

with *u* = (year – 1900)/100, or the time measured in centuries since 1900.

This formula was based on a study of the post-1650 observations of the Sun, the Moon and the planets by Spencer Jones (1939).

This single-parabolic relation (the influence of the “small fluctuations” was assumed to be negligible in the historical past) was used by Meeus in his *Astronomical Formulæ for Calculators* (1979, 1982) and in the lunar and solar eclipse tables of Mucke & Meeus (198?) and Meeus & Mucke (198?). It is also adopted in the PC program SunTracker Pro (Zephyr Services, 19??).

Astronomical Ephemeris (1960)

In 1960, a slightly modified version of the above relation was adopted in the *Astronomical Ephemeris*:

$$\text{Delta T (sec)} = 24.349 + 72.3165 * u + 29.949 * u^2 + \text{small fluctuations}$$

with *u* = (year – 1900)/100, or the time measured in centuries since 1900.

Tuckerman (1962, 1964) & Goldstine (1973)

The tables of Tuckerman (1962, 1964) list the positions of the Sun, the Moon and the planets at 5- and 10-day intervals from 601 B.C. to A.D. 1649. The listed positions are for 19h 00m (mean) local time at Babylon/Baghdad (*i.e.* near sunset) or 16h 00m GMT. From the difference in the adopted solar theory (Leverrier, 1857) with that of Newcomb (1895), Stephenson & Houlden (1981) and Houlden & Stephenson (1986) derived the following Delta T relation that is implicitly used in the Tuckerman tables:

$$\text{Delta T (sec)} = 4.87 + 35.06 * u + 36.79 * u^2$$

with *u* = (year – 1900)/100, or the time measured in centuries since 1900.

Morrison & Stephenson (1982)

Single-parabolic fit by L.V. Morrison & F.R. Stephenson.

$$\text{Delta T (sec)} = -15 + 32.5 * u^2$$

with u = (year – 1810)/100, or the time measured in centuries since 1810.

This relation was adopted in Bretagnon & Simon's *Planetary Programs and Tables from –4000 to +2800* (1986) and in the PC planetarium program RedShift (Maris Multimedia, 1994-2000).

Stephenson & Morrison (1984)

Double-parabolic fit by F.R. Stephenson & L.V. Morrison.

$$\text{Delta T (sec)} = 1360 + 320 * u + 44.3 * u^2 \qquad (-391 < \text{year} < +948)$$

and

$$\text{Delta T (sec)} = 25.5 * u^2 \qquad (+948 < \text{year} < +1600)$$

with u = (year – 1800)/100, or the time measured in centuries since 1800.

Stephenson & Houlden (1986)

Double-parabolic fit by F.R. Stephenson & M.A. Houlden,

$$\text{Delta T (sec)} = 1830 - 405 * t + 46.5 * t^2 \qquad (\text{year} < +948)$$

with t = (year – 948)/100, or the time measured in centuries since A.D. 948, and

$$\text{Delta T (sec)} = 22.5 * u^2 \qquad (+948 < \text{year} < +1600)$$

with u = (year – 1850)/100, or the time measured in centuries since 1850.

This relation is used in the PC planetarium program Guide 7 (Project Pluto, 1999).

Espenak (1987, 1989)

The following single-parabolic relation closely approximates the Delta T values given by Fred Espenak in his *Fifty*

Year Canon of Solar Eclipses 1986 – 2035 (1987) and in his *Fifty Year Canon of Lunar Eclipses 1986 – 2035* (1989).

Delta T (sec) = 65.0 + 76.15 * u + 41.6 * u^2

with u = (year – 2000)/100, or the time measured in centuries since 2000.

This relation should not be used before around 1950 or after around 2100.

Borkowski (1988)

The following single-parabolic fit was obtained by K.M. Borkowski from an analysis of 31 solar eclipse records from 2137 B.C. to A.D. 1715:

Delta T (sec) = 40 + 35.0 * u^2

with u = (year – 1625)/100, or the time measured in centuries since 1625.

The solar eclipse records were compared with the ELP 2000-85 lunar theory of Chapront-Touzé & Chapront (1988) which adopts a tidal acceleration parameter of –23.8946 arcsec/cy/cy.

Note that Borkowski's Delta T relation is strongly biased by the inclusion of speculative Delta T values inferred from two very early but highly doubtful solar eclipse records: the so-called Ugarit eclipse (dated to 3 May 1375 B.C. by Borkowski) and the legendary Chinese eclipse of Xi-Ho (22 October 2137 B.C.) mentioned in the *Shu Jing*.

Chapront-Touzé & Chapront (1991)

The following double-parabolic fit was adopted by Michelle Chapront-Touzé & Jean Chapront in the shortened version of the ELP 2000-85 lunar theory in their *Lunar Tables and Programs from 4000 B.C. to A.D. 8000* (1991):

Delta T (sec) = 2177 + 495 * u + 42.4 * u^2 (–391 < year < +948)

and

Delta T (sec) = 102 + 100 * u + 23.6 * u^2 (+948 < year < +1600)

with u = (year – 2000)/100, or the time measured in centuries since 2000.

The relations are based on those of Stephenson & Morrison (1984), but slightly modified to make them compatible with the tidal acceleration parameter of –23.8946 arcsec/cy/cy adopted in the ELP 2000-85 lunar theory.

Chapront, Chapront-Touzé & Francou (1997)

Six years later, Jean Chapront, Michelle Chapront-Touzé & G. Francou published an improved set of orbital constants for the ELP 2000-85 lunar theory in which they adopted a revised lunar acceleration parameter of –25.7376 arcsec/cy/cy to obtain a close fit the JPL DE 403 theory of the planets.

$$\text{Delta T (sec)} = 2177 + 497 * u + 44.1 * u^2 \qquad (–391 < \text{year} < +948)$$

and

$$\text{Delta T (sec)} = 102 + 102 * u + 25.3 * u^2 \qquad (+948 < \text{year} < +1600)$$

with u = (year – 2000)/100, or the time measured in centuries since 2000.

This relation is also recommended by Jean Meeus in the second edition of his *Astronomical Algorithms* (1998), but in order to avoid a discontinuity of about 37 seconds with the observed values around 2000, he suggests adding the linear term:

$$+0.37 * (\text{year} – 2100) \qquad (+2000 < \text{year} < +2100)$$

JPL Horizons

The JPL Solar System Dynamics Group of the NASA Jet Propulsion Laboratory (California Institute of Technology) supports an interactive website JPL Horizons for calculating high-precision positions of the solar system bodies from the most recent and accurate algorithms. For dates before 1620, the JPL Horizons website uses the following Delta T relations:

$$\text{Delta T (sec)} = 31.0 * t^2 \qquad (–2999 < \text{year} < +948)$$

with t = (year – 1820)/100, or the time measured in centuries since 1820, and

$$\text{Delta T (sec)} = 50.6 + 67.5 * u + 22.5 * u^2 \qquad (+948 < \text{year} < +1620)$$

with u = (year – 2000)/100, or the time measured in centuries since 2000. The source of the pre-948 relation is unclear, the post-948 relation was taken from Stephenson & Houlden (1986).

Note that their relations imply a 526.6-second jump in Delta T around A.D. 948.

Javascript Delta T Calculator

With the following Javascript calculator, values for Delta T predicted from the various relations suggested in the past can be displayed simultaneously for comparison.

Delta T Calculator

Year	Lunar acceleration parameter ("/cy/cy)	Press for a new calculation
2002	-26.0	C

IAU (1952)	
***Astronomical Ephemeris* (since 1960)**	
Tuckerman & Goldstine (1962, 1964, 1973)	
Morrison & Stephenson (1982)	
Stephenson & Morrison (1984)	
Stephenson & Houlden (1986)	
Espenak (1987, 1989)	
Borkowski (1988)	
Chapront-Touzé & Chapront (1991)	
Chapront, Chapront-Touzé & Francou (1997)	
JPL Horizons	

(Delta T is given in minutes)

The influence of the lunar acceleration parameter can also be studied by changing its nominal value of –26.0 arcsec/cy/cy. Note that the following values were adopted in the original Delta T relations:

- –22.44 in the IAU (1952) and the *Astronomical Ephemeris* (since 1960) relations
- –26.0 in the relations derived by Stephenson and his co-workers
- –23.8946 in the relations derived by Borkowski (1988) and Chapront-Touzé & Chapront (1991) (DE200)
- –25.7376 in the relations derived by Chapront *et al.* (1997) and adopted on the JPL Horizons website (DE403)

Delta T in Astronomical Software and PC Planetarium Programs

Most PC planetarium programs implicitly use one of the above Delta T algorithms in their software but usually do not display the calculated value of Delta T or bother to give any details on the algorithm adopted.

One of the few laudable exceptions is Guide (Project Pluto, 1993-1999) that displays the value used for Delta T in the Quick Info section in the Help menu. Version 7 claims to use the single-parabolic fit of Morrison & Stephenson (1982), but in fact uses the double-parabolic fit of Stephenson & Houlden (1986).

The treatment of Delta T on the JPL Horizons website is inconsistent. One of their relations is based on a lunar acceleration parameter of –26.0 arcsec/cy/cy while their ephemerides are based on a value of –25.7376 arcsec/cy/cy. Their relations also imply a nearly 9-minute jump in Delta T around A.D. 948.

References

- Borkowski, K.M., “ELP 2000-85 and the Dynamical Time – Universal Time Relation”, *Astronomy and Astrophysics*, **205** (1988), L8-L10.
- Bretagnon, P. & Simon, J.-L., *Planetary Programs and Tables from –4000 to +2800* (Willmann-Bell, Richmond, 1986).
- Brouwer, D., “A Study of the Changes in the Rate of Rotation of the Earth”, *Astronomical Journal*, **57** (1952), 125-146.
- Chapront, J., Chapront-Touzé, M. & Francou, G., *Nouvelles expressions des termes séculaires dans Lunar Tables and Programs from 4000 B.C. to A.D. 8000* (Bureau des Longitudes, Paris, 1997 [= *Notes Scientifiques et Techniques du Bureau des Longitudes*, no. S055]).
- Chapront, J., Chapront-Touzé, M. & Francou, G., “Determination of the Lunar Orbital and Rotational Parameters and of the Ecliptic Reference System Orientation from LLR Measurements and IERS Data”, *Astronomy and Astrophysics*, **343** (1999), 624-633.
- Chapront-Touzé, M. & Chapront, J., “ELP 2000-85: A Semi-Analytical Lunar Ephemeris Adequate for Historical Times”, *Astronomy and Astrophysics*, **190** (1988), 342-352.
- Chapront-Touzé, M. & Chapront, J., *Lunar Tables and Programs from 4000 B.C. to A.D. 8000* (Willmann-Bell, Richmond, 1991), pp. 6-7.
- Clemence, G.M., “On the System of Astronomical Constants”, *Astronomical Journal*, **53** (1948), 169-179.
- Clemence, G.M., “The Concept of Ephemeris Time: A Case of Inadvertent Plagiarism”, *Journal for the History of Astronomy*, **2** (1971), 73-79.
- Danjon, A., “Le temps: Sa définition pratique, sa mesure”, *l’Astronomie: Bulletin de la Société Astronomique de France*, **43** (1929), 13-23.
- Dickey, J.O., “Earth Rotation Variations from Hours to Centuries”, in: I. Appenzeller (ed.), *Highlights of Astronomy: Vol. 10* (Kluwer Academic Publishers, Dordrecht/Boston/London, 1995), pp. 17-44.
- Dickey, J.O., Bender, P.L., Faller, J.E., Newhall, X.X., Ricklefs, R.L., Ries, J.G., Shelus, P.J., Veillet, C.,

Whipple, A.L., Wiant, J.R., Williams, J.G. & Yoder, C.F., "Lunar Laser Ranging: A Continuing Legacy of the Apollo Program", *Science*, **265** (1994), 482-490.

- Espenak, F., *Fifty Year Canon of Solar Eclipses 1986 – 2035* (NASA, Washington, 1987 [= *NASA Reference Publication*, nr. 1178]).
- Espenak, F., *Fifty Year Canon of Lunar Eclipses 1986 – 2035* (NASA, Washington, 1989 [= *NASA Reference Publication*, nr. 1216]) [not seen].
- Gross, R.S., "A Combined Day-of-Length Series Spanning 1832-1997: LUNAR 97", *Physics of the Earth and Planetary Interiors*, **123** (2001), 65-76.
- Houlden, M.A. & Stephenson, F.R., *A Supplement to the Tuckerman Tables* (American Philosophical Society, Philadelphia, 1986 [= *Memoirs of the American Philosophical Society*, **170**]).
- Jordi, C., Morrison, L.V., Rosen, R.D., Salstein, D.A. & Rosselló, G., "Fluctuations in the Earth's Rotation since 1830 from High-Resolution Astronomical Data", *Geophysical Journal International*, **117** (1994), 811-818.
- Krasinsky, G.A., Saramonova, E.Y., Sveshnikov, M.L. & Sveshnikova, E.S., "Universal Time, Lunar Tidal Deceleration and Relativistic Effects from Observations of Transits, Eclipses and Occultations in the XVIII-XX Centuries", *Astronomy and Astrophysics*, **145** (1985), 90-96.
- Leverrier, U.-J., "Théorie et tables du mouvement apparent du soleil", *Annales de l'Observatoire impérial de Paris*, **4** (1857) [not seen].
- Martin, Ch.F., *A Study of the Rate of Rotation of the Earth from Occultations of Stars by the Moon 1627-1860* (Yale diss., [New Haven], 1969) [not seen].
- McCarthy, D.D. & Babcock, A.K., "The Length of Day since 1656", *Physics of the Earth and Planetary Interiors*, **44** (1986), 281-292.
- Meeus, J., *Astronomical Formulæ for Calculators* (Volkssterrenwacht Urania V.Z.W. en Vereniging voor Sterrenkunde V.Z.W., Hove, 1979 [= *Monografiëen over Astronomie en Astrofysica*, nr. 4]), chapter 5.
- Meeus, J., *Astronomical Formulæ for Calculators*, 2nd ed. (Willmann-Bell, Richmond, 1982), chapter 5.
- Meeus, J., *Astronomical Formulæ for Calculators*, 3rd ed. (Willmann-Bell, Richmond, 198?), chapter ? [not seen].
- Meeus, J., *Astronomical Formulæ for Calculators*, 4th ed. (Willmann-Bell, Richmond, 1988), chapter ? [not seen].
- Meeus, J., *Astronomical Algorithms* (Willmann-Bell, Richmond, 1991), chapter 9.
- Meeus, J., *Astronomical Algorithms*, 2nd ed. (Willmann-Bell, Richmond, 1998), chapter 10.
- Meeus, J., "The Effect of Delta T on Astronomical Calculations", *Journal of the British Astronomical Association*, **108** (1998), 154-156 [reprinted in Meeus (2002), chapter 68].
- Meeus, J., *More Mathematical Astronomy Morsels* (Willmann-Bell, Richmond, 2002).
- Montenbruck, O., *Practical Ephemeris Calculations* (Springer-Verlag, Berlin [etc.], 1989), pp. 35-37 [not seen].
- Montenbruck, O. & Pfleger, T., *Astronomy on the Personal Computer* (Springer-Verlag, Berlin [etc.], 1990), pp. ??-?? & ??? [not seen].
- Montenbruck, O. & Pfleger, T., *Astronomy on the Personal Computer*, 2nd ed. (Springer-Verlag, Berlin

[etc.], 1994), pp. 41-45 & 187 [not seen].

- Montenbruck, O. & Pfleger, T., *Astronomy on the Personal Computer*, 3rd ed. (Springer-Verlag, Berlin [etc.], 199?), pp. ??-?? & ??? [not seen].
- Montenbruck, O. & Pfleger, T., *Astronomy on the Personal Computer*, 4th ed. (Springer-Verlag, Berlin [etc.], 2000), pp. 41-44 & 187-188.
- Morrison, L.V., "Re-Determination of the Decade Fluctuations in the Rotation of the Earth in the Period 1861-1978", *Geophysical Journal of the Royal Astronomical Society*, **58** (1979), 349-360.
- Morrison, L.V., "An Analysis of Lunar Occultations in the Years 1943-1974 for Corrections to the Constants in Brown's Theory, the Right Ascension System of the FK4, and Watts' Lunar-Profile Datum", *Monthly Notices of the Royal Astronomical Society*, **187** (1979), 41-82.
- Morrison, L.V. & Stephenson, F.R., "Determination of "decade" fluctuations in the Earth's Rotation 1620-1978", in: E.M. Gaposchkin & B. Kolaczek (eds.), *Reference Coordinate Systems for Earth Dynamics: Proceedings of the 56th Colloquium of the International Astronomical Union held in Warsaw, Poland, September 8-12, 1980* (D. Reidel Publ. Co., Dordrecht, 1981 [= *Astrophysics and Space Science Library*, nr. 86]), pp. 181-185 [not seen].
- Morrison, L.V. & Stephenson, F.R., "Secular and Decade Fluctuations in the Earth's Rotation: 700 BC - AD 1978", in: W. Fricke & G. Teleki (eds.), *Sun and Planetary System: Proceedings of the Sixth European Regional Meeting in Astronomy, Held in Dubrovnik, Yugoslavia, 19-23 October 1981* (D. Reidel Publ. Co., Dordrecht, 1982 [= *Astrophysics and Space Science Library*, nr. 96]), pp. 173-178.
- Morrison, L.V. & Ward, C.G., "An Analysis of the Transits of Mercury: 1677-1973", *Monthly Notices of the Royal Astronomical Society*, **173** (1975), 183-206.
- Newcomb, S., "Tables of the Motion of the Earth on its Axis and around the Sun", *Astronomical Papers prepared for the use of the American Ephemeris and Nautical Almanac*, **6**, pt. 1 (1895) [not seen].
- Sadler, D.H., "Ephemeris Time", *Occasional Notes of the Royal Astronomical Society*, **3** (1954), 103-113.
- Schmadel, L.D. & Zech, G., "Polynomial Approximations for the Correction Delta T = E.T. – U.T. in the Period 1800-1975", *Acta Astronomica*, **29** (1979), 101-104 [= *Mitteilungen des Astronomischen Rechen-Instituts Heidelberg*, Serie A, nr. ??].
- Schmadel, L.D. & Zech, G., "Emperical Transformations from U.T. to E.T. for the Period 1800 – 1988", *Astronomische Nachrichten*, **309** (1988), 219-221.
- Seidelmann, P.K. (ed.), *Explanatory Supplement to the Astronomical Almanac* (University Science Books, Sausalito, 1992), chapters 2 & 4.
- Sitter, W. de, "On the Secular Accelerations and the Fluctuations of the Longitudes of the Moon, the Sun, Mercury and Venus", *Bulletin of the Astronomical Institutes of the Netherlands*, **4** (1927), 21-38.
- Spencer Jones, H., "The Rotation of the Earth, and the Secular Accelerations of the Sun, Moon and Planets", *Monthly Notices of the Royal Astronomical Society*, **99** (1939), 541-558.
- Standish, E.M., "The Observational Basis for JPL's DE200, the Planetary Ephemerides of the Astronomical Almanac", *Astronomy and Astrophysics*, **233** (1990), 252-271.
- Stephenson, F.R., *Historical Eclipses and Earth's Rotation* (Cambridge University Press, Cambridge, 1997).
- Stephenson, F.R. & Houlden, M.A., "The Accuracy of Tuckerman's Solar and Planetary Tables", *Journal for the History of Astronomy*, **12** (1981), 133-138.

- Stephenson, F.R. & Houlden, M.A., *Atlas of Historical Eclipse Maps: East Asia 1500 BC – AD 1900* (Cambridge University Press, Cambridge [etc.], 1986), pp. ix-xi.
- Stephenson, F.R., Jones, J.E. & Morrison, L.V., "The Solar Eclipse Observed by Clavius in A.D. 1567", *Astronomy and Astrophysics*, **322** (1997), 347-351.
- Stephenson, F.R. & Lieske, J.H., "Changes in the Earth's Rate of Rotation between A.D. 1672 and 1806 as deduced from Solar Eclipse Timings", *Astronomy and Astrophysics*, **200** (1988), 218-224.
- Stephenson, F.R. & Morrison, L.V., "Long-Term Changes in the Rotation of the Earth: 700 BC to AD 1980", *Philosophical Transactions of the Royal Society of London*, Ser. A, **313** (1984), 47-70.
- Stephenson, F.R. & Morrison, L.V., "Long-Term Fluctuations in the Earth's Rotation: 700 BC to AD 1990", *Philosophical Transactions of the Royal Society of London*, Ser. A, **351** (1995), 165-202.
- *Transactions of the International Astronomical Union* (???, ???, 195?), vol. 8, pp. 88 & 91 [not seen].
- Williams, J.G., "???", *Journal of Geophysical Research (Planets)*, **106** (2001), 27933-27968 [not seen].

Suggestions for corrections or additions will be greatly appreciated.

Robert H. van Gent

[document last updated on 20 April 2002]
