Polynomial Expressions for Delta T (ΔT)

Adapted from "Five Millennium Canon of Solar Eclipses" [Espenak and Meeus]

Using the ΔT values derived from the historical record and from direct observations (see: **Table 1** and **Table 2**), a series of polynomial expressions have been created to simplify the evaluation of ΔT for any time during the interval -1999 to +3000.

We define the decimal year "y" as follows:

```
y = year + (month - 0.5)/12
```

This gives "y" for the middle of the month, which is accurate enough given the precision in the known values of ΔT. The following polynomial expressions can be used calculate the value of ΔT (in seconds) over the time period covered by of the **Five Millennium Canon of Solar Eclipses: -1999 to +3000**.

Before the year -500, calculate:

```
ΔT = -20 + 32 * u^2
where:  u = (year-1820)/100
```

Between years -500 and +500, we use the data from **Table 1**, except that for the year -500 we changed the value 17190 to 17203.7 in order to avoid a discontinuity with the previous formula at that epoch. The value for ΔT is given by a polynomial of the 6th degree, which reproduces the values in **Table 1** with an error not larger than 4 seconds:

```
ΔT = 10583.6 - 1014.41 * u + 33.78311 * u^2 - 5.952053 * u^3
        - 0.1798452 * u^4 + 0.022174192 * u^5 + 0.0090316521 * u^6
where: u = y/100
```

Between years +500 and +1600, we again use the data from **Table 1** to derive a polynomial of the 6th degree.

```
ΔT = 1574.2 - 556.01 * u + 71.23472 * u^2 + 0.319781 * u^3
        - 0.8503463 * u^4 - 0.005050998 * u^5 + 0.0083572073 * u^6
where: u = (y-1000)/100
```

Between years +1600 and +1700, calculate:

```
ΔT = 120 - 0.9808 * t - 0.01532 * t^2 + t^3 / 7129
where:  t = y - 1600
```

Between years +1700 and +1800, calculate:

```
ΔT = 8.83 + 0.1603 * t - 0.0059285 * t^2 + 0.00013336 * t^3 - t^4 / 1174000
where: t = y - 1700
```

Between years +1800 and +1860, calculate:

```
ΔT = 13.72 - 0.332447 * t + 0.0068612 * t^2 + 0.0041116 * t^3 - 0.00037436 * t^4
        + 0.0000121272 * t^5 - 0.0000001699 * t^6 + 0.000000000875 * t^7
where: t = y - 1800
```

Between years 1860 and 1900, calculate:

```
ΔT = 7.62 + 0.5737 * t - 0.251754 * t^2 + 0.01680668 * t^3
        -0.0004473624 * t^4 + t^5 / 233174
where: t = y - 1860
```

Between years 1900 and 1920, calculate:

```
ΔT = -2.79 + 1.494119 * t - 0.0598939 * t^2 + 0.0061966 * t^3 - 0.000197 * t^4
where: t = y - 1900
```

Between years 1920 and 1941, calculate:

```
ΔT = 21.20 + 0.84493*t - 0.076100 * t^2 + 0.0020936 * t^3
where: t = y - 1920
```

Between years 1941 and 1961, calculate:

```
ΔT = 29.07 + 0.407*t - t^2/233 + t^3 / 2547
where: t = y - 1950
```

Between years 1961 and 1986, calculate:

```
ΔT = 45.45 + 1.067*t - t^2/260 - t^3 / 718
where: t = y - 1975
```

Between years 1986 and 2005, calculate:

```
ΔT = 63.86 + 0.3345 * t - 0.060374 * t^2 + 0.0017275 * t^3 + 0.000651814 * t^4
        + 0.00002373599 * t^5
where: t = y - 2000
```

Between years 2005 and 2050, calculate:

```
ΔT = 62.92 + 0.32217 * t + 0.005589 * t^2
where: t = y - 2000
```

This expression is derived from estimated values of ΔT in the years 2010 and 2050. The value for 2010 (66.9 seconds) is based on a linearly extrapolation from 2005 using 0.39 seconds/year (average from 1995 to 2005). The value for 2050 (93 seconds) is linearly extrapolated from 2010 using 0.66 seconds/year (average rate from 1901 to 2000).

Between years 2050 and 2150, calculate:

```
ΔT = -20 + 32 * ((y-1820)/100)^2 - 0.5628 * (2150 - y)
```

The last term is introduced to eliminate the discontinuity at 2050.

After 2150, calculate:

```
ΔT = -20 + 32 * u^2
where:  u = (year-1820)/100
```

All values of ΔT based on Morrison and Stephenson [2004] assume a value for the Moon's secular acceleration of -26 arcsec/cy^2. However, the ELP-2000/82 lunar ephemeris employed in the **Canon** uses a slightly different value of -25.858 arcsec/cy^2. Thus, a small correction "c" must be added to the values derived from the polynomial expressions for ΔT before they can be used in the **Canon**

```
c = -0.000012932 * (y - 1955)^2
```

Since the values of ΔT for the interval 1955 to 2005 were derived independent of any lunar ephemeris, no correction is needed for this period.

The **uncertainty in ΔT** over this period can be estimated from scatter in the measurements.

References

Morrison, L. and Stephenson, F . R., "Historical Values of the Earth's Clock Error ΔT and the Calculation of Eclipses" , J. Hist. Astron., Vol. 35 Part 3, August 2004, No. 120, pp 327-336 (2004).

Stephenson F.R and Houlden M.A., *Atlas of Historical Eclipse Maps* , Cambridge Univ .Press., Cambridge, 1986.

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