The ‘Friday Effect’

Leif Svalgaard 10/28/2008

The SORCE website http://lasp.colorado.edu/sorce/instruments/tim/tim_flight_calib.htm#orbital_corrections describes the corrections to TSI to reduce the values to 1 AU. It is stated that:

Orbital Corrections Are Very Accurately Known

Corrections to the data to account for the varying distance between the Earth and the Sun during the year are calculated based on JPL ephemeris VSOP87 data, which has very high precision and contributes <1 ppm to the TIM uncertainty. Doppler corrections due to the spacecraft's line-of-sight velocity relative to the Sun are made based on spacecraft position and velocity data, which are very accurately tracked and propagated from NORAD TLE/SGP4 and similarly contribute <1 ppm to the TIM uncertainty. Corrections for both distance and radial velocity to the Sun are applied in ground data processing.

Let TS_{Iobs} be the observed TSI [presumably without any corrections] and TSI_{1AU} be TSI reduced to 1 AU, [columns 10 and 5, respectively]. I now form the ratio $C = TSI_{1AU}/TSI_{obs}$ which should be the [total] correction, including both the distance effect and the Doppler correction. Let r be the [Geocentric=>Heliocentric] distance to the Sun as calculated by JPL, then to first approximation $C = r^2$. Forming the ratio $F = C / r^2$ we eliminate the distance effect and should now have a measure of the radial velocity effect. Because F is very close to 1, we now form the quantity $G = F – 1$. Figure 1 shows G for every day since 2004.0.

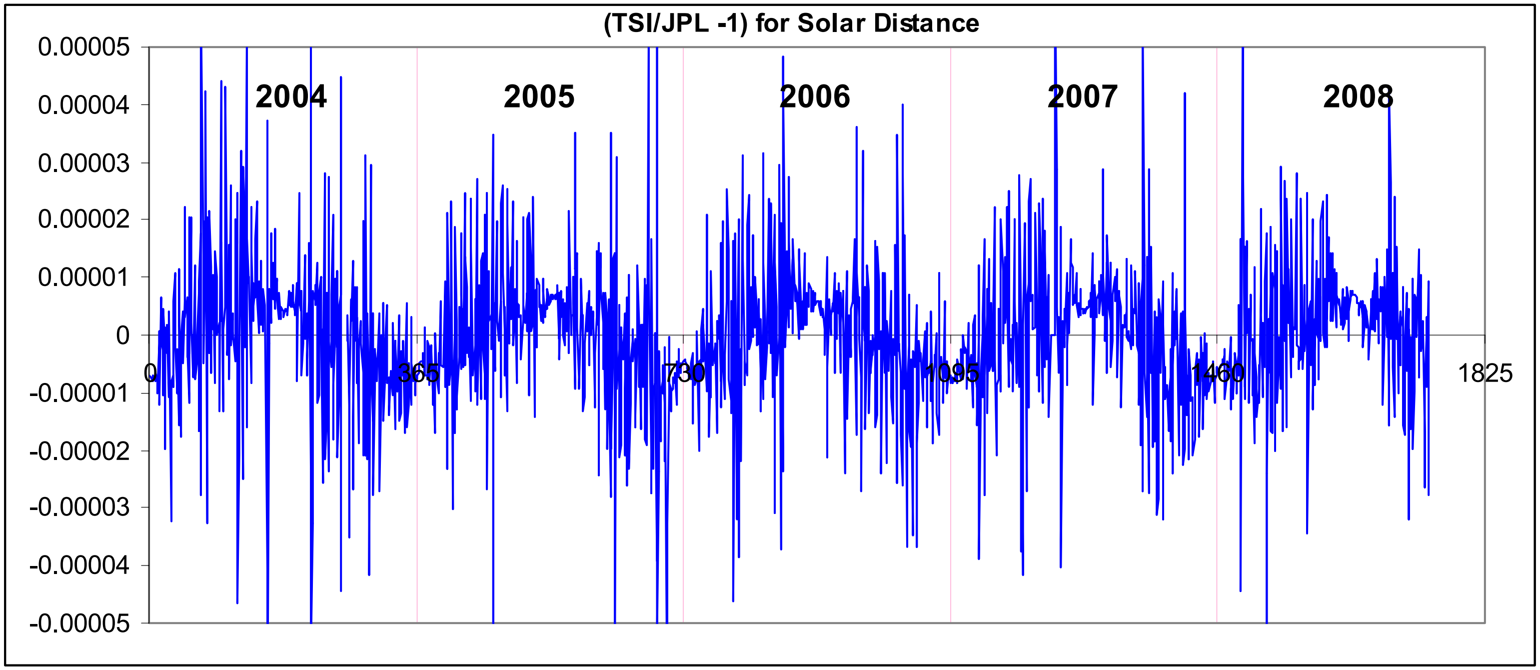


Figure 1.

There is a clear annual variation with maximum near aphelion and minimum near perihelion. I identify those with the radial velocity correction [but don’t know if this is correct]

In addition there are [much larger] variations of short [of the order of one day] duration superposed on the annual curve. A few of those are ‘noise’ in the sense that the daily [average] values are not taken from strictly and fully time-wise equidistant ‘raw’ measurements. A handful of very large outliers have been suppressed.

But most are periodic with a period of 7.00 days [determined from the FFT power spectrum]. This is clearly seen by eye in the following several Figures. The peaks coincide with [UT] Fridays [marked by dark blue diamonds, although at times they can be a few hours off.

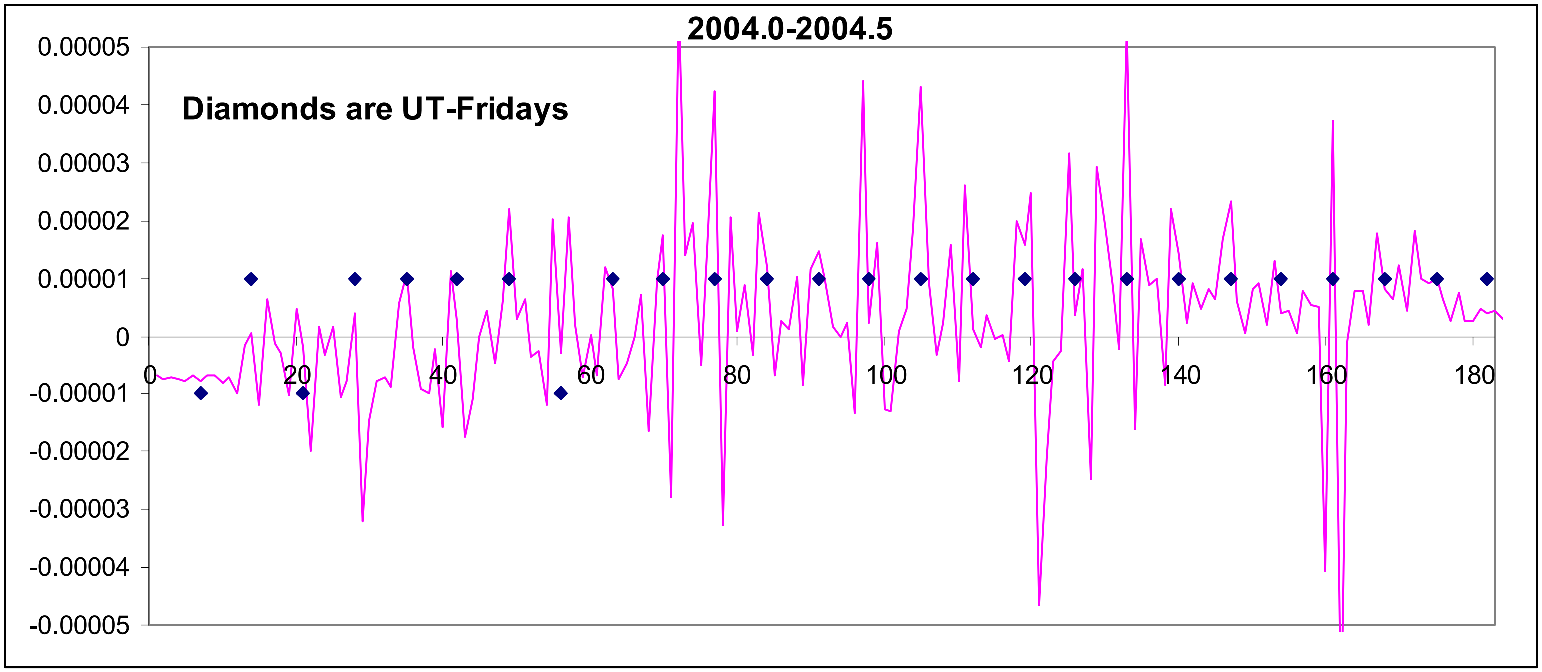


Figure 2 (a)

There is a sign convention here. If the G-value on a given Friday is positive, the Friday-diamond is plotted at $+1\cdot10^{-5}$, otherwise at $-1\cdot10^{-5}$.

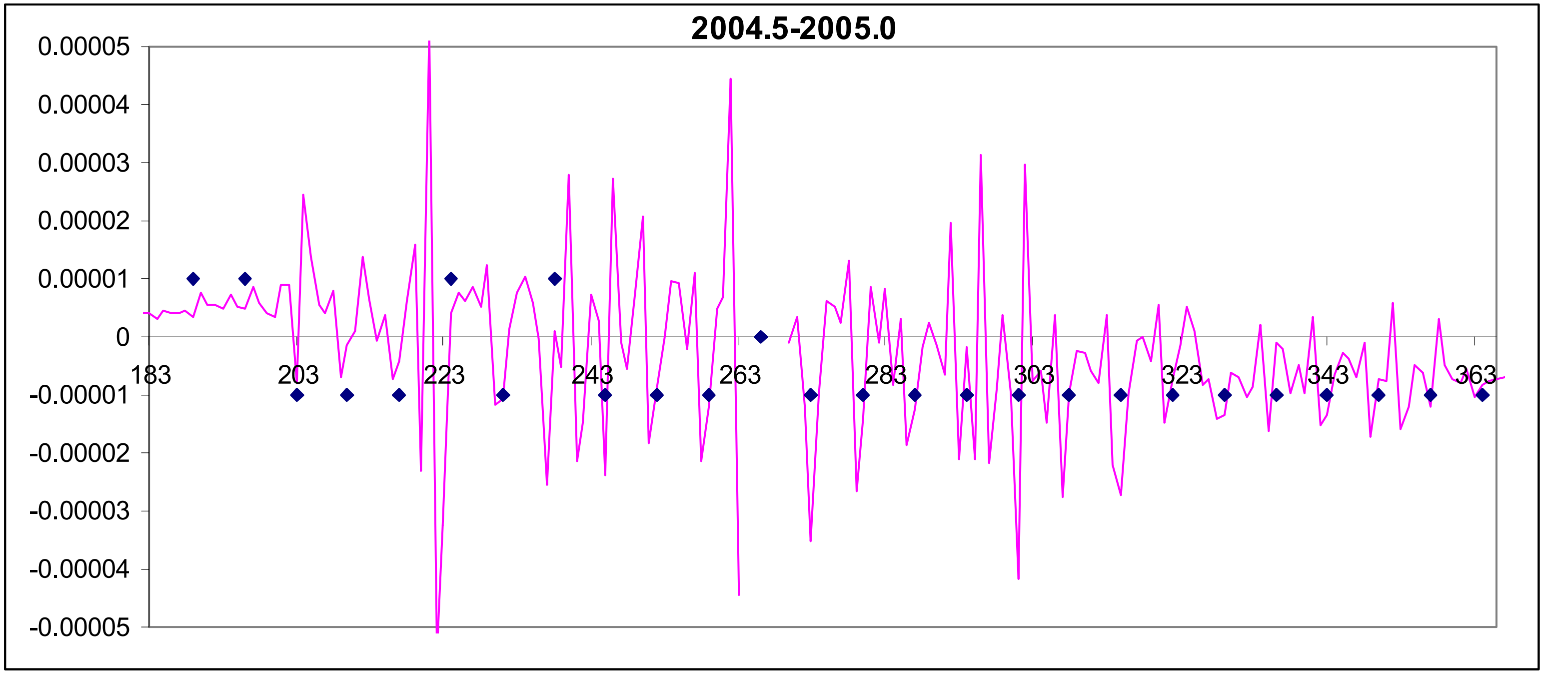


Figure 2 (b)

This ‘Friday’ effect seems to follow the sign of G. The effect is absent for about a month at both aphelion and perihelion. One interpretation is that the effect depends on dr/dt, which would also explain why the scatter at perihelion and aphelion is so small.

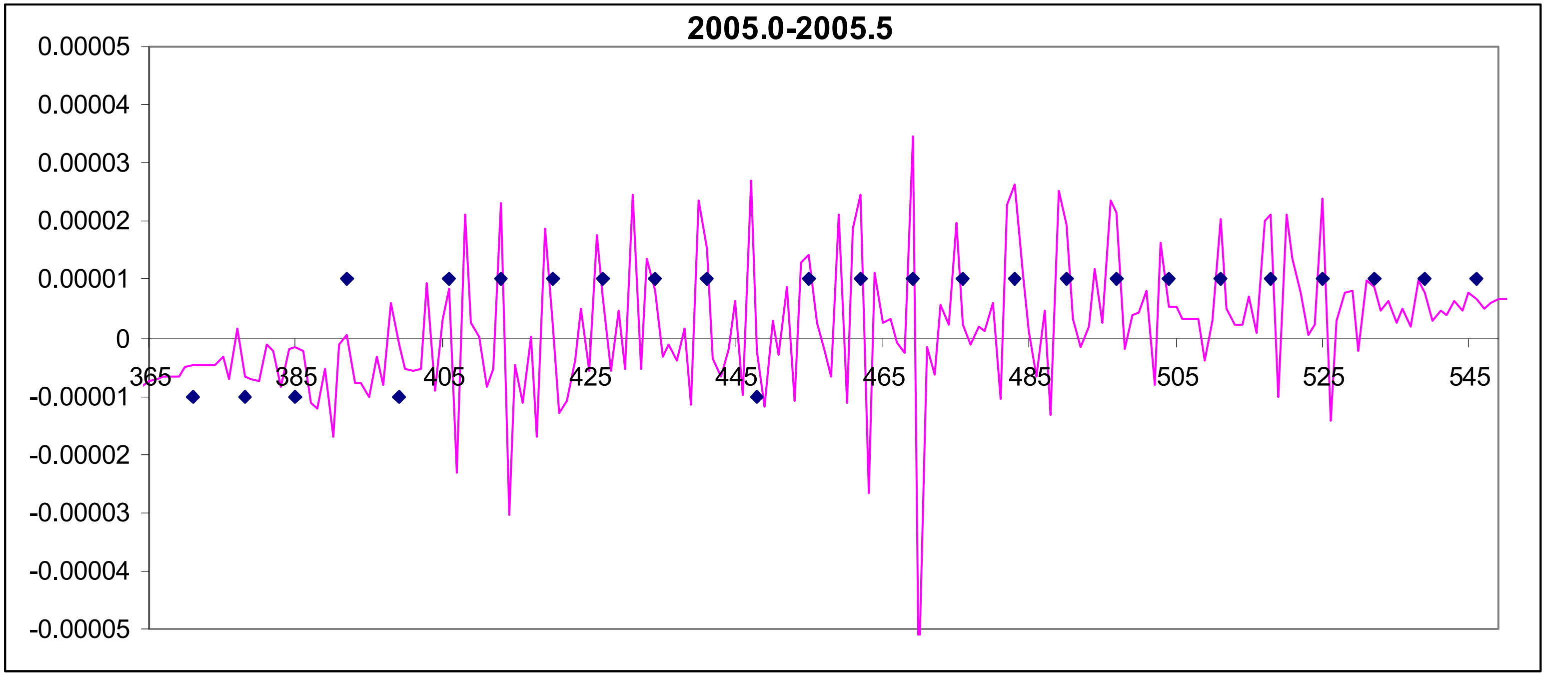


Figure 2 (c)

Here [Figure 2 (c)] is a particularly clean example.

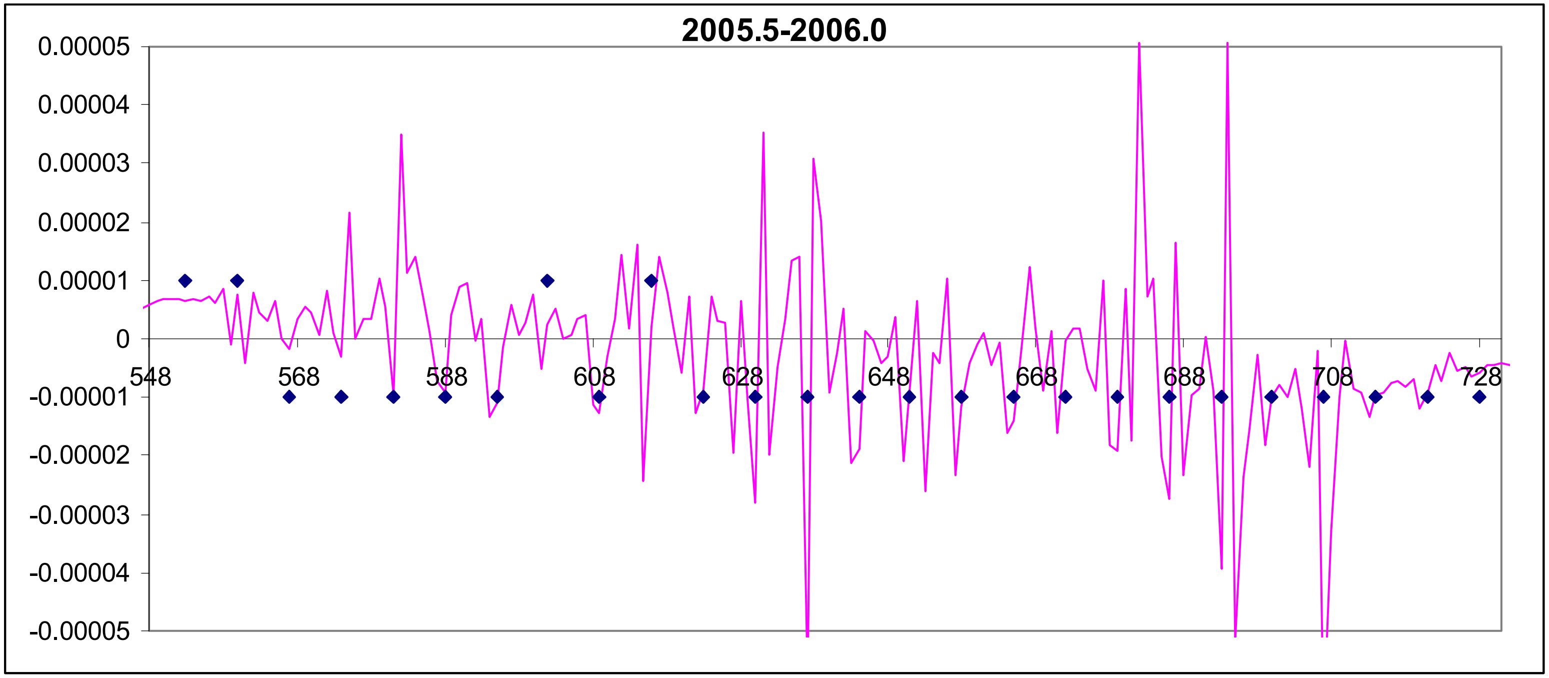


Figure 2 (d)

But the ‘Friday’ effect seems to be a permanent and clear feature.

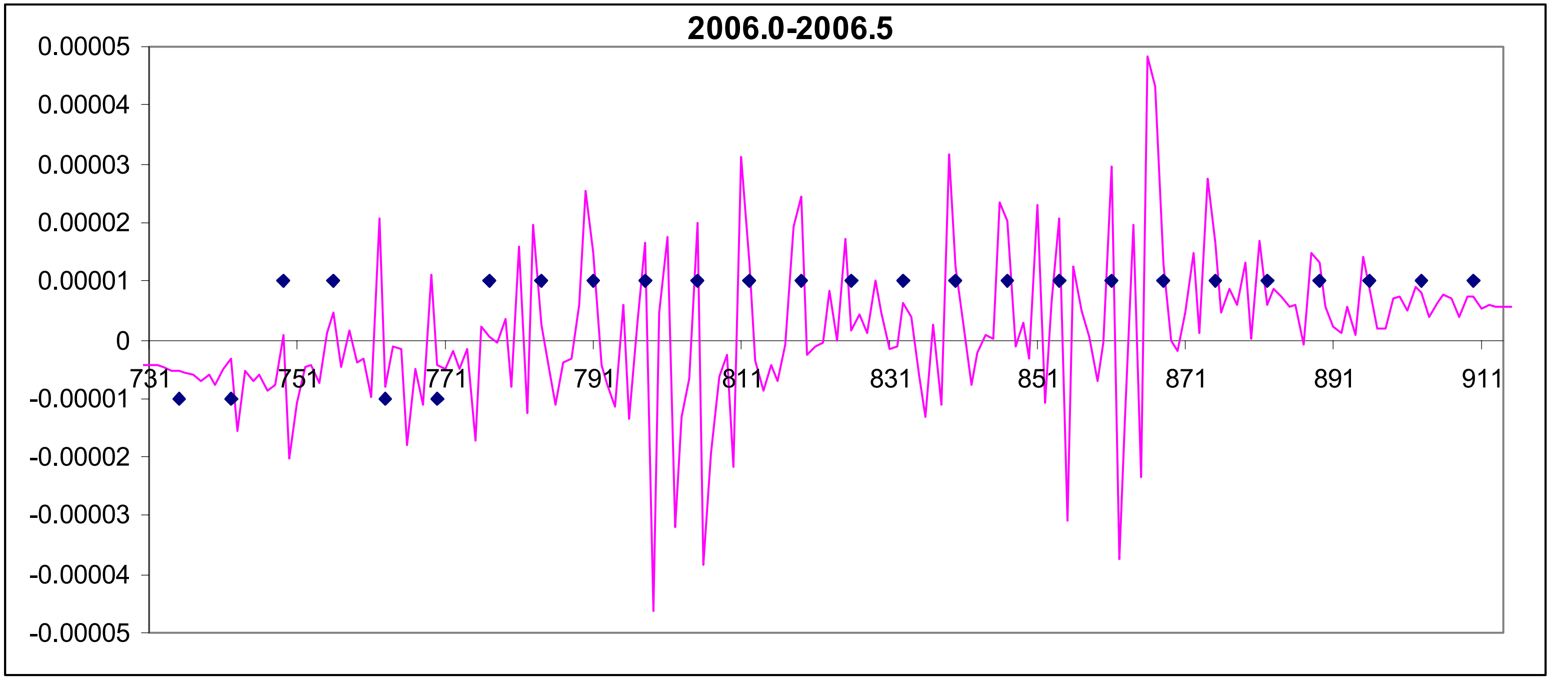


Figure 2 (e)

At times [Figure 2 (e) there is some extra noise.

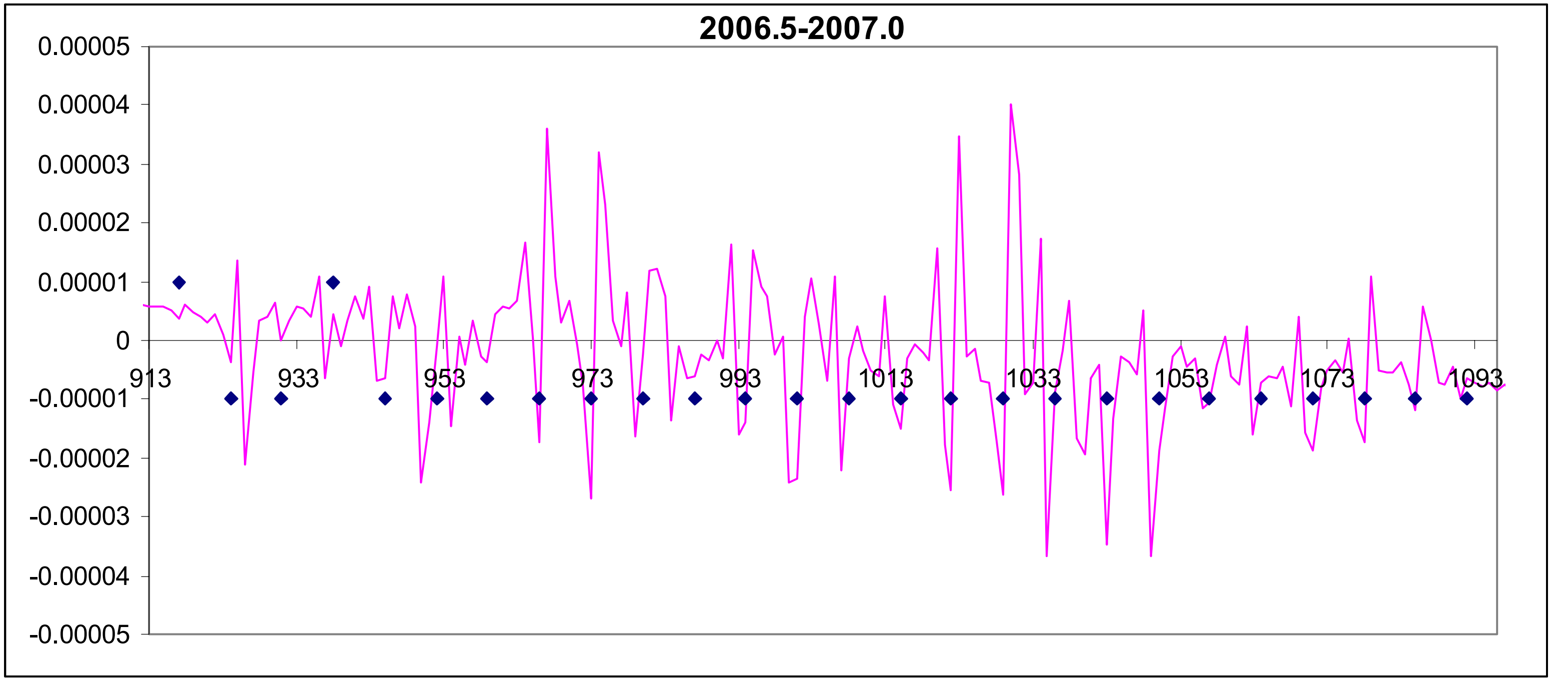

2006.5-2007.0
0.00005
0.00004
0.00003
0.00002
0.00001
0
-0.00001
-0.00002
-0.00003
-0.00004
-0.00005
913
933
953
973
993
1013
1033
1053
1073
1093

Figure 2 (f)

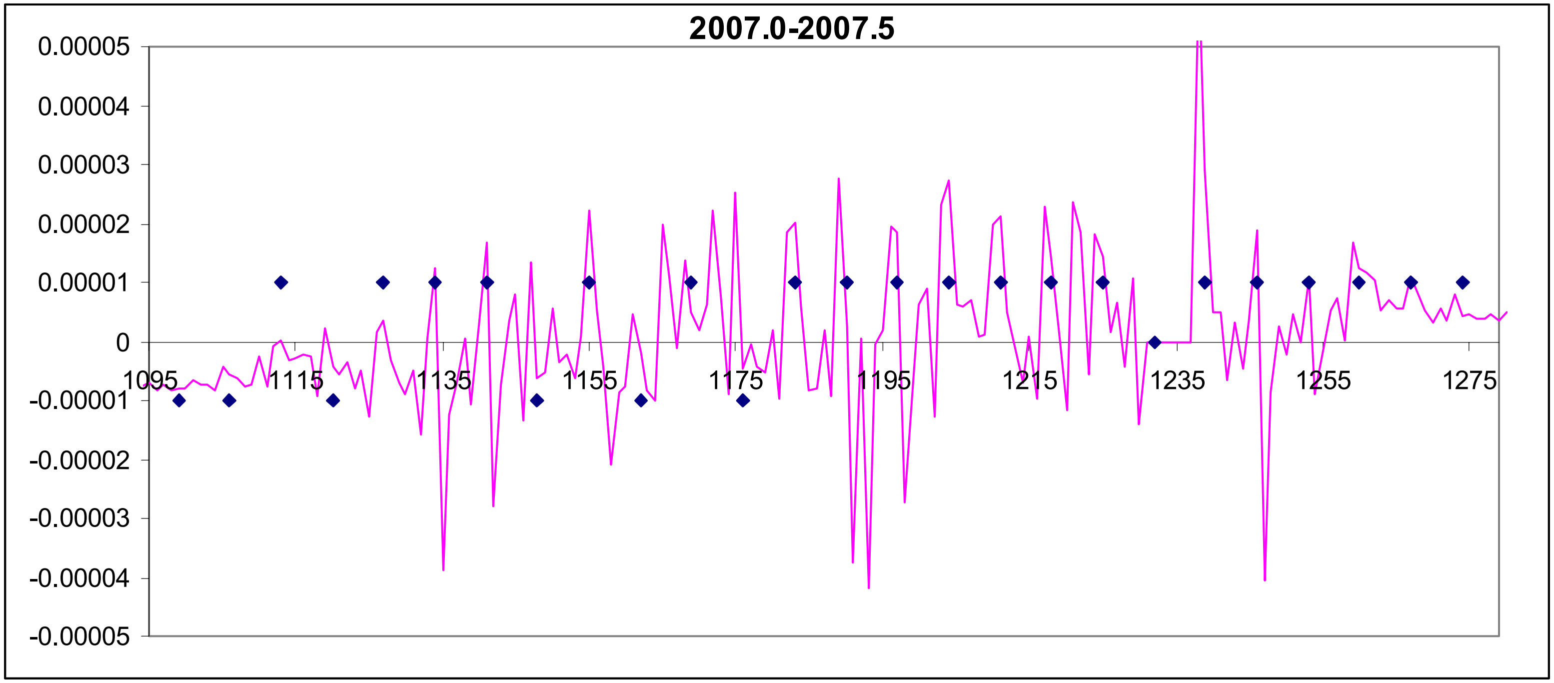

2007.0-2007.5
0.00005
0.00004
0.00003
0.00002
0.00001
0
-0.00001
-0.00002
-0.00003
-0.00004
-0.00005
1095
1115
1135
1155
1175
1195
1215
1235
1255
1275

Figure 2 (g)

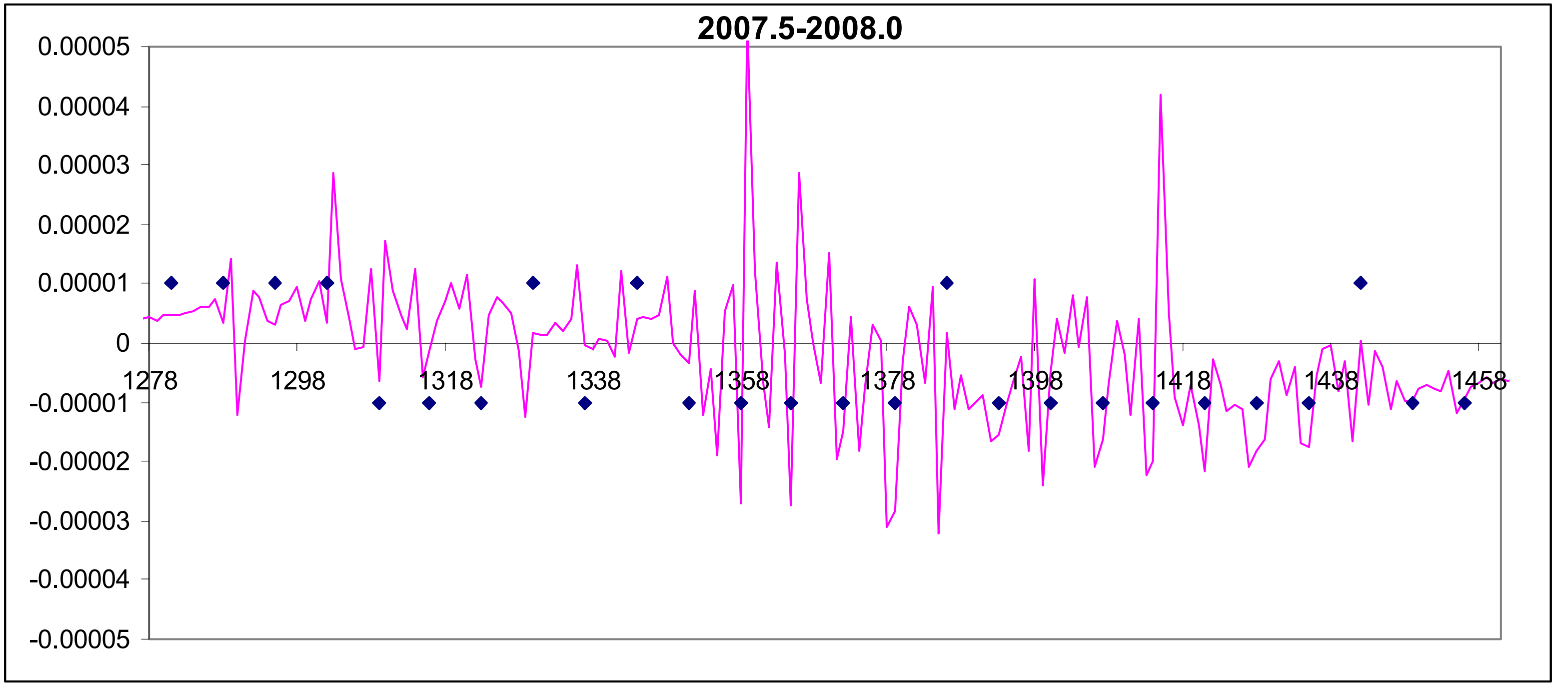

2007.5-2008.0
0.00005
0.00004
0.00003
0.00002
0.00001
0
-0.00001
-0.00002
-0.00003
-0.00004
-0.00005
1278
1298
1318
1338
1358
1378
1398
1418
1438
1458

Figure 2 (h)

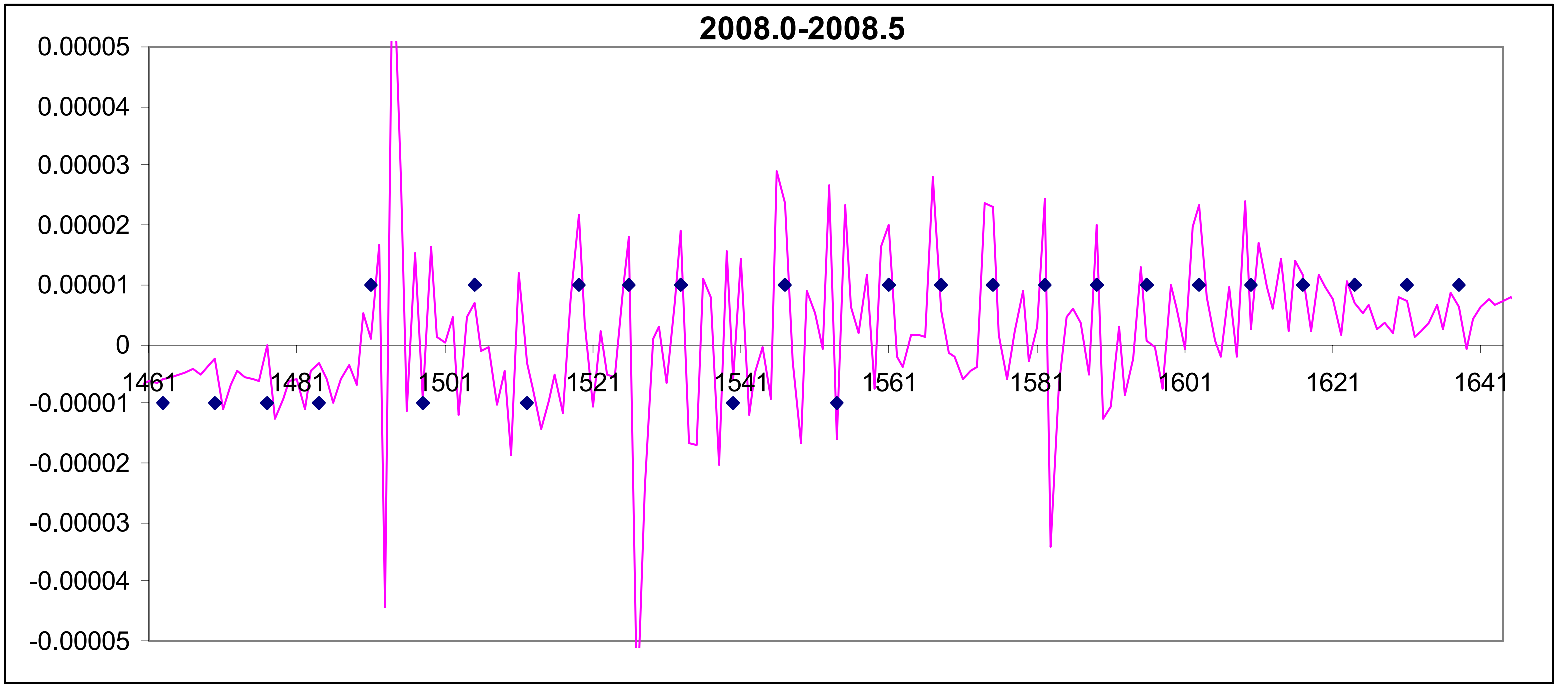


Figure 2 (i)

The ‘Friday’ effect seems to persist throughout the mission.

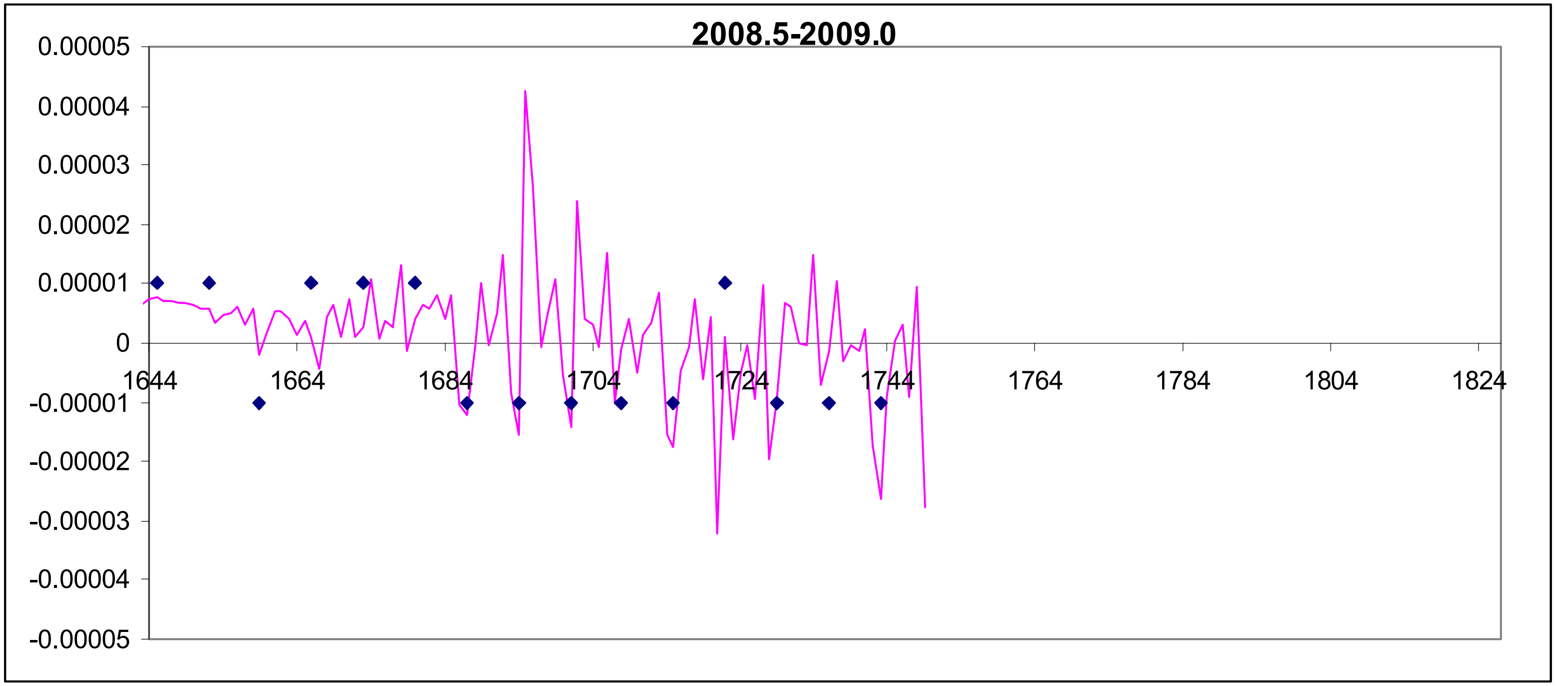
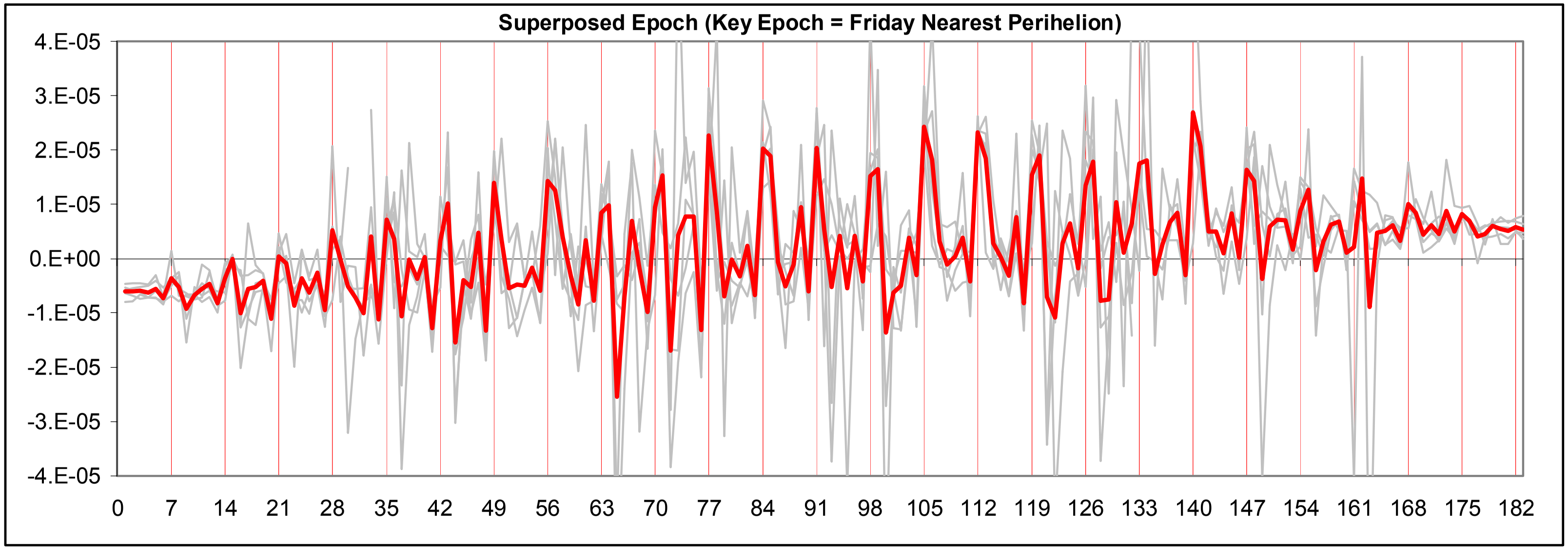
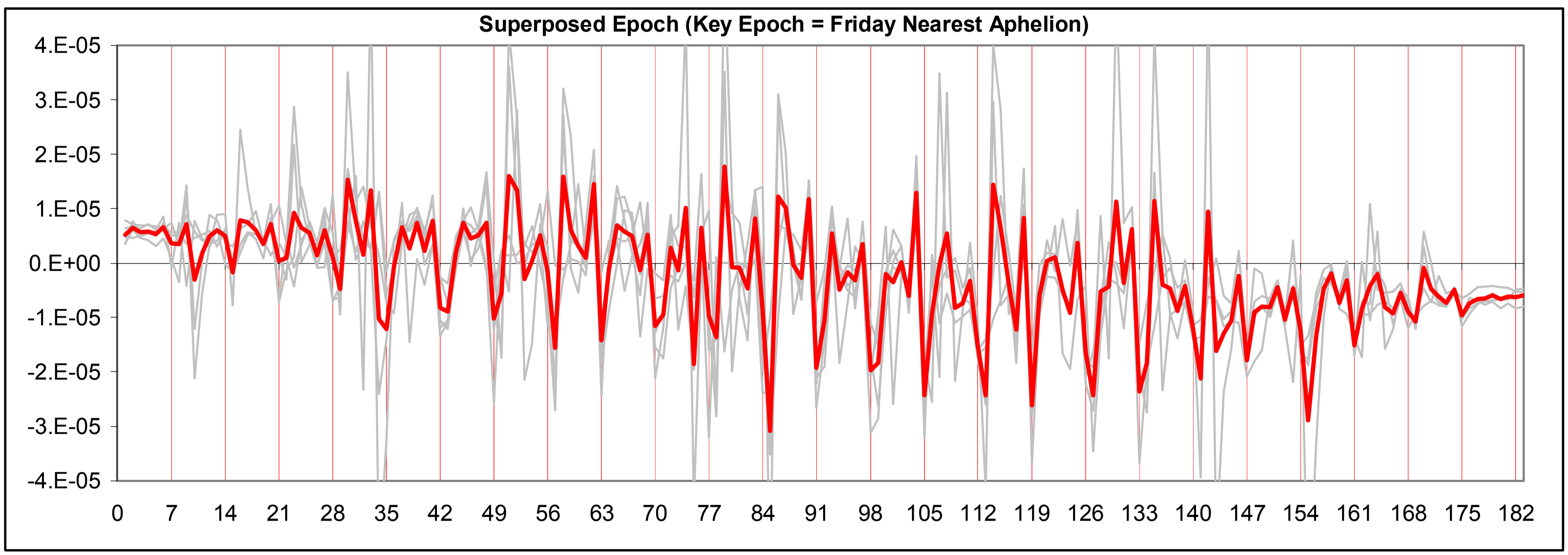


Figure 2 (j)

The ‘Friday’ effect is large, $2 \cdot 10^{-5}$, or 20 ppm.

Figure 3 [next page] shows superposed epoch analyses with the key times at the Fridays nearest to Perihelion and Aphelion, respectively. Vertical red lines marks the Fridays. Note the positive Friday peaks on the first panel and the negative Friday peaks on the second panel.


Superposed Epoch (Key Epoch = Friday Nearest Perihelion)
4.E-05
3.E-05
2.E-05
1.E-05
0.E+00
-1.E-05
-2.E-05
-3.E-05
-4.E-05
0 7 14 21 28 35 42 49 56 63 70 77 84 91 98 105 112 119 126 133 140 147 154 161 168 175 182


Superposed Epoch (Key Epoch = Friday Nearest Aphelion)
4.E-05
3.E-05
2.E-05
1.E-05
0.E+00
-1.E-05
-2.E-05
-3.E-05
-4.E-05
0 7 14 21 28 35 42 49 56 63 70 77 84 91 98 105 112 119 126 133 140 147 154 161 168 175 182

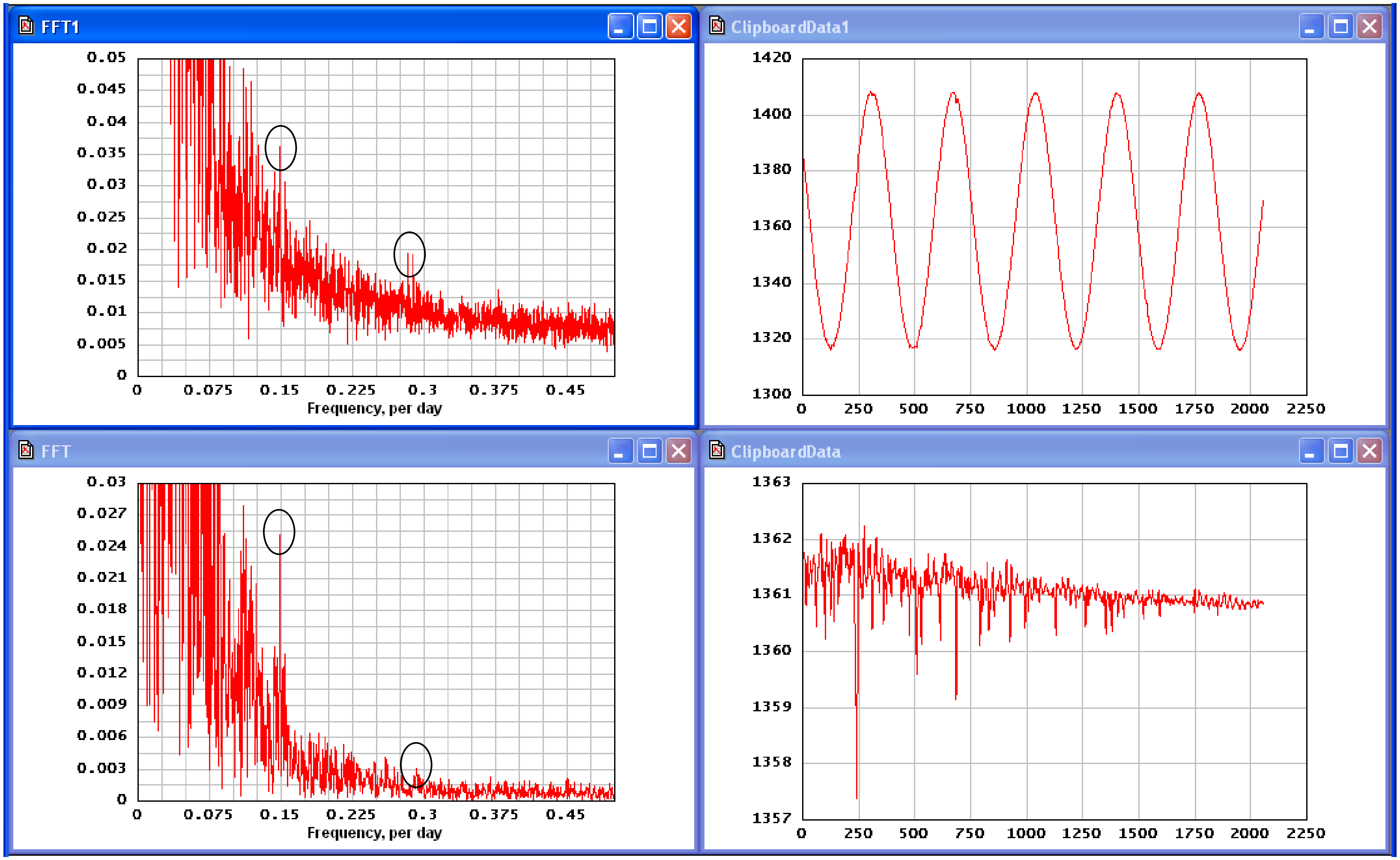


Figure 4

The Friday effect is also seen [ovals] in the power spectrum of both the 'raw' observed values [top] and in the values corrected to 1 AU [bottom]. Even the second harmonic shows up, complete with splitting [in the raw TSI], due to the yearly modulation.

The ‘Friday’ Effect, Revisited

11/7/2008

The only reasonable place a ‘Friday’ effect can creep in is an uneven coverage dependence on weekdays. Figure 1 [below] shows the FFT power spectrum of the standard deviation of the ‘data time’[I first removed the mean]. There is a [very sharp] excess of power every seven days [frequency 0.1429 days] and precisely at twice and thrice that [below the Nyquist cutoff]. Such uneven coverage makes the simple linear interpolation I had performed dubious. As the TIM-team actually does, the corrections have to take place on every individual measurement. So there is the explanation of the ‘Friday’-effect. Note that ‘Friday’ now is in quotes.

Non-linear interpolation will still work if done a bit more carefully. Using a three-point Lagrange interpolation [I tried a few other more ‘sophisticated’ ones – it doesn’t make any further difference] the ‘Friday’ effect [almost – see below] disappears. Figure 2 shows the G-function after I went to the more accurate non-linear interpolation, where $G = (TSI_{1AU}/TSI_{obs})/ r^2 - 1$.

The ‘8-minute’ light-time 1.6 ppm effect is clearly seen. I don’t know why its phase is about a week later than perihelion/aphelion.

There is an additional modulation of 0.25 ppm that has a period of 29.54 days. This is a lunar [synodic month 29.53 days] effect. Obviously, the Moon has an influence on the Sun-Earth distance, so this effect may not be a surprise. What is a puzzle is how it can have been left out.

The FFT spectrum of the TSI1AU [as given by the TIM-team] shows power at 7 days [Figure 3], so there may still be some little gremlin somewhere, but my original ‘Friday’ effect was clearly due to a combination of a Friday effect in coverage and my [too naïve] interpolation.

Sorry to have caused inconvenience, but at least I have learnt something, especially how good the TIM data actually is.

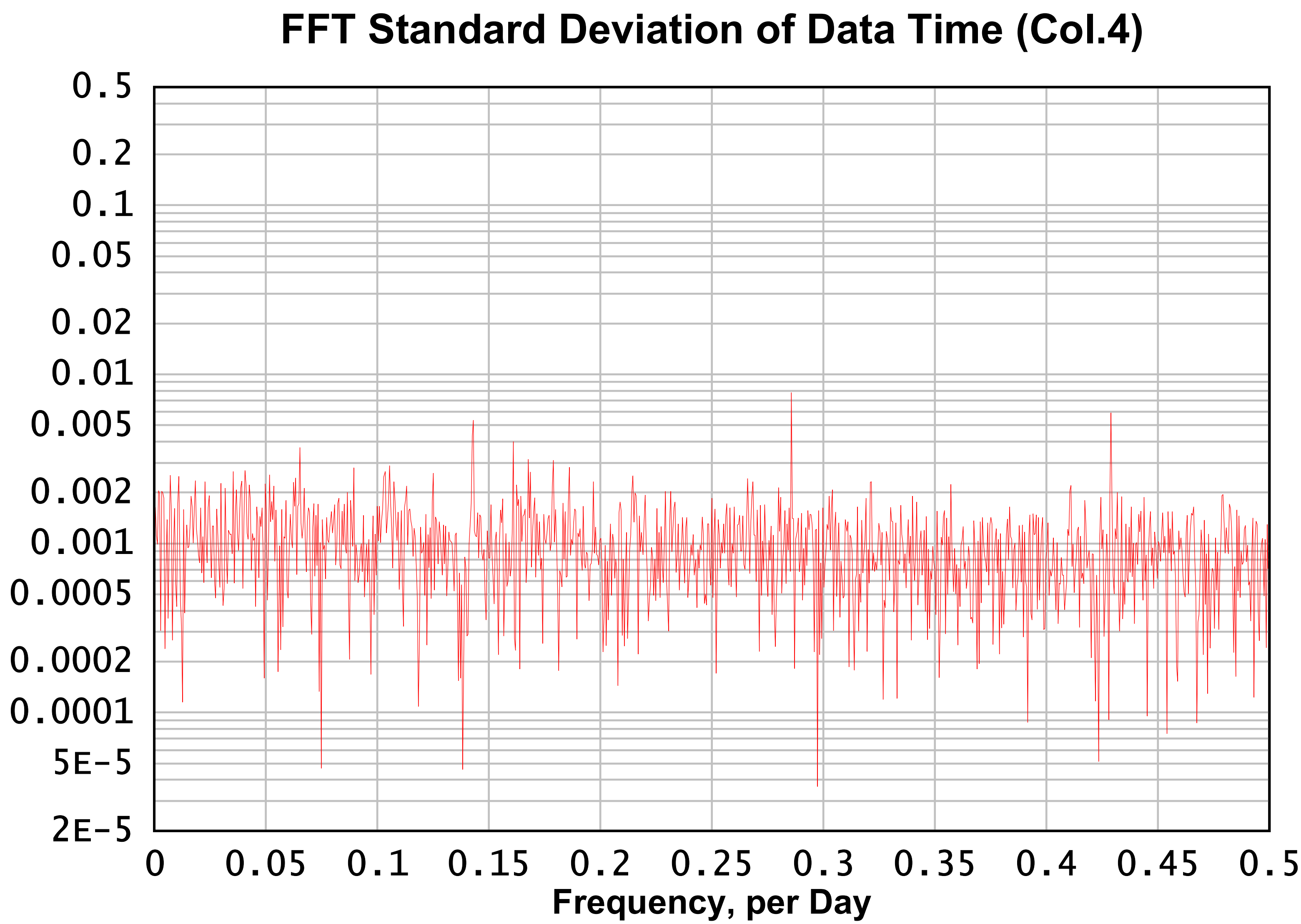

FFT Standard Deviation of Data Time (Col.4)
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
5E-5
2E-5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Frequency, per Day

Figure 1

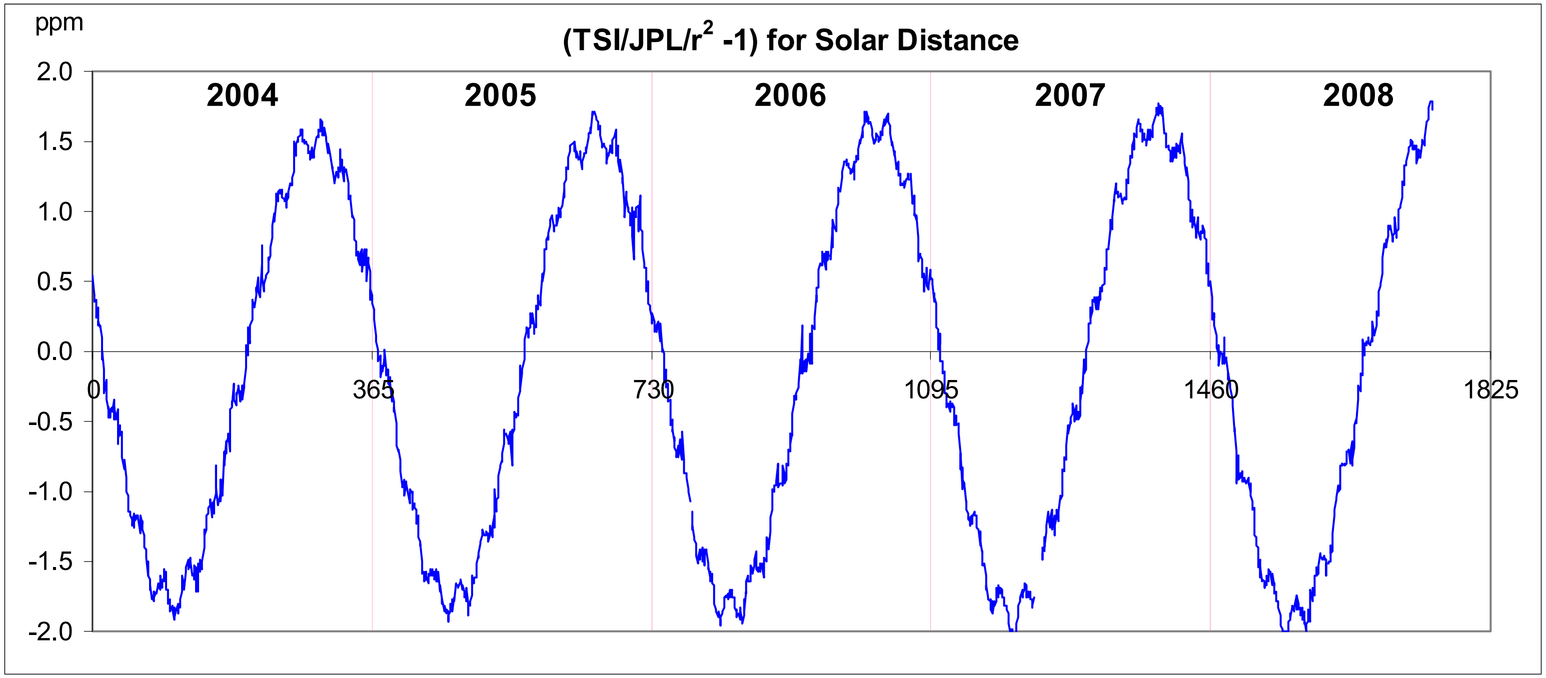

ppm
(TSI/JPL/r² -1) for Solar Distance
2004
2005
2006
2007
2008
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
365
730
1095
1460
1825

Figure 2

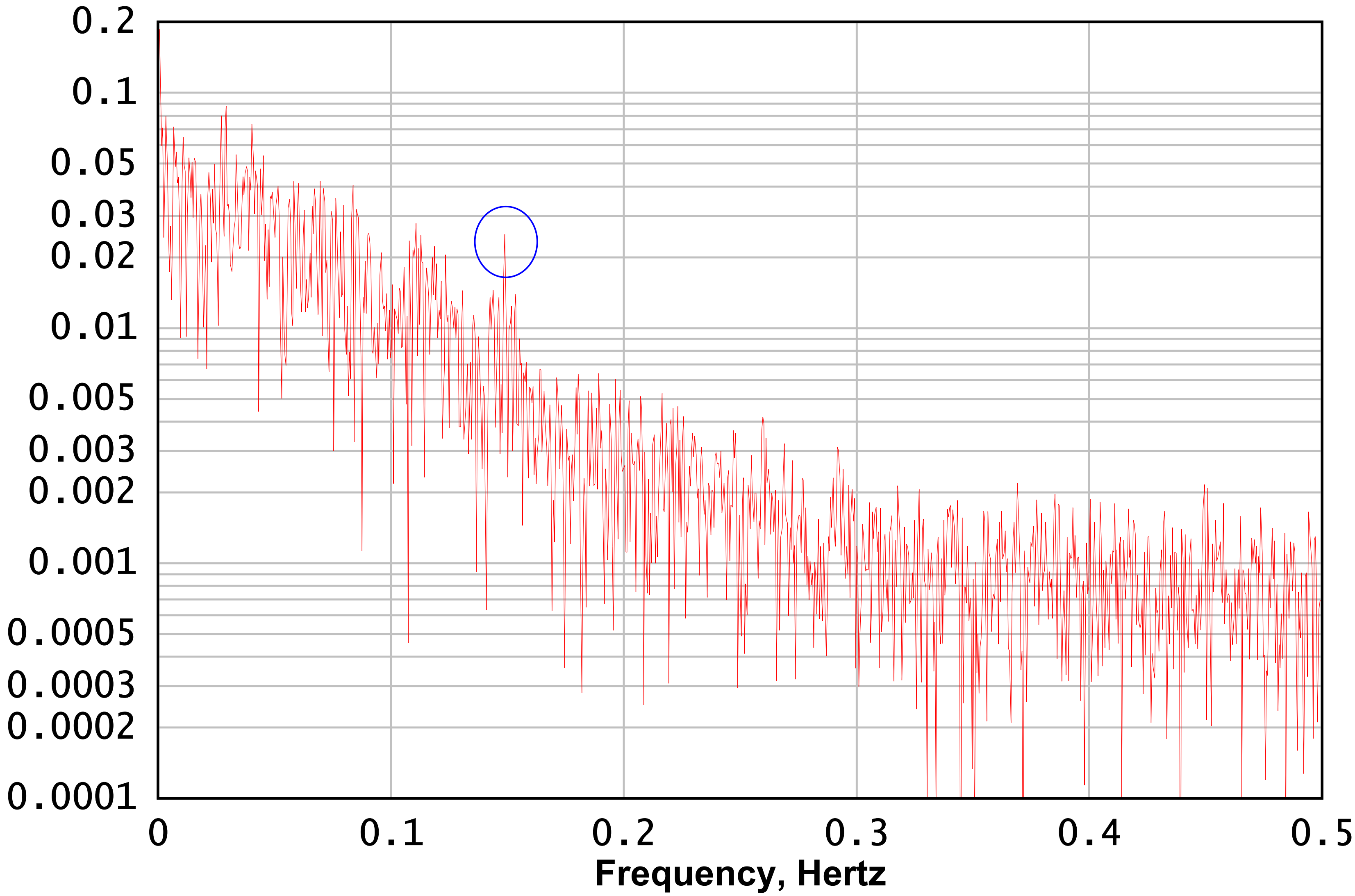
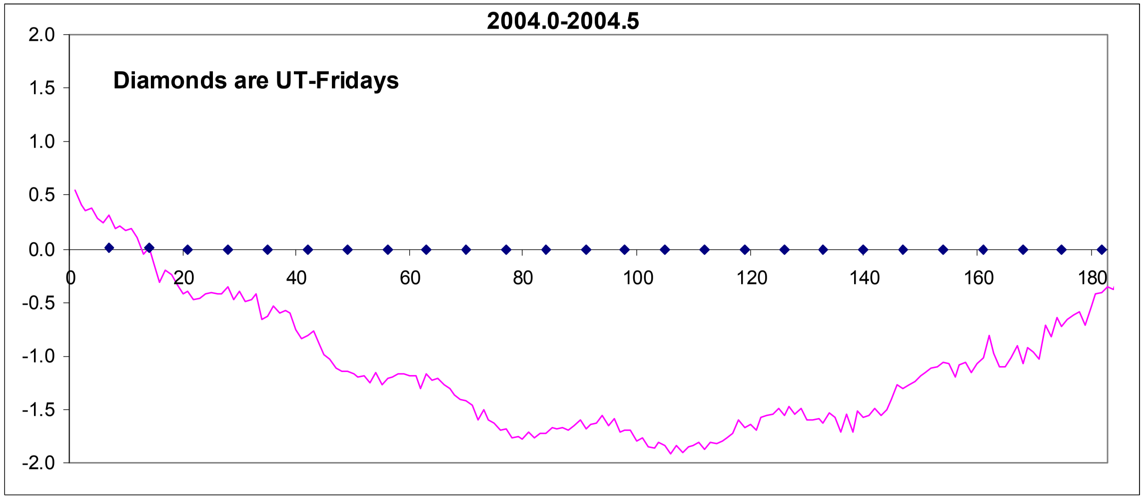
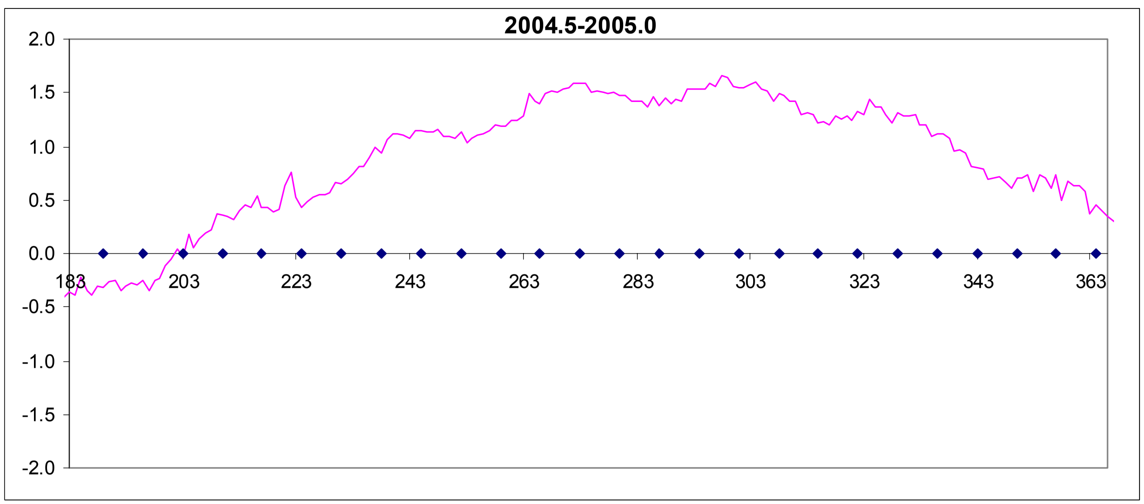
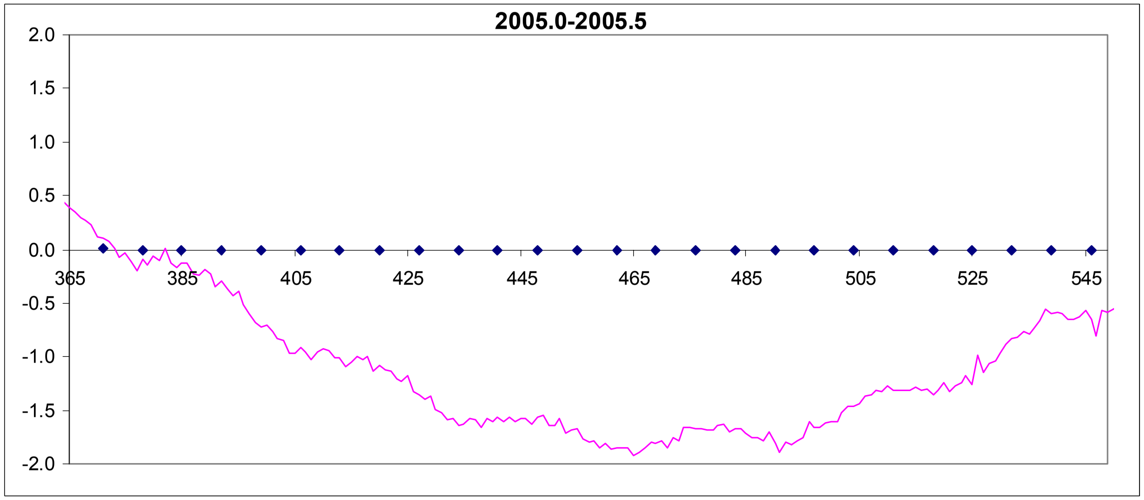

0.2
0.1
0.05
0.03
0.02
0.01
0.005
0.003
0.002
0.001
0.0005
0.0003
0.0002
0.0001
0
0.1
0.2
0.3
0.4
0.5
Frequency, Hertz

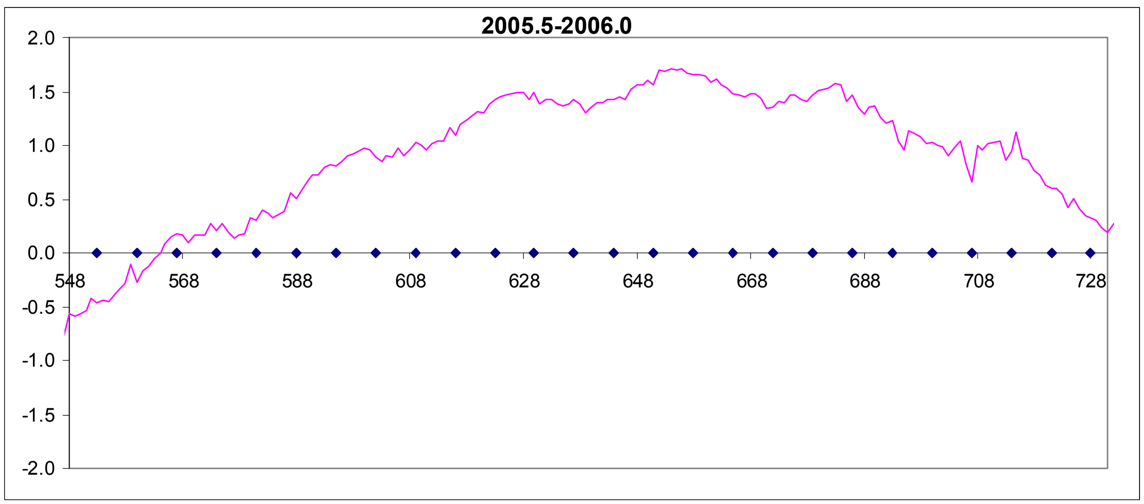
Figure 3

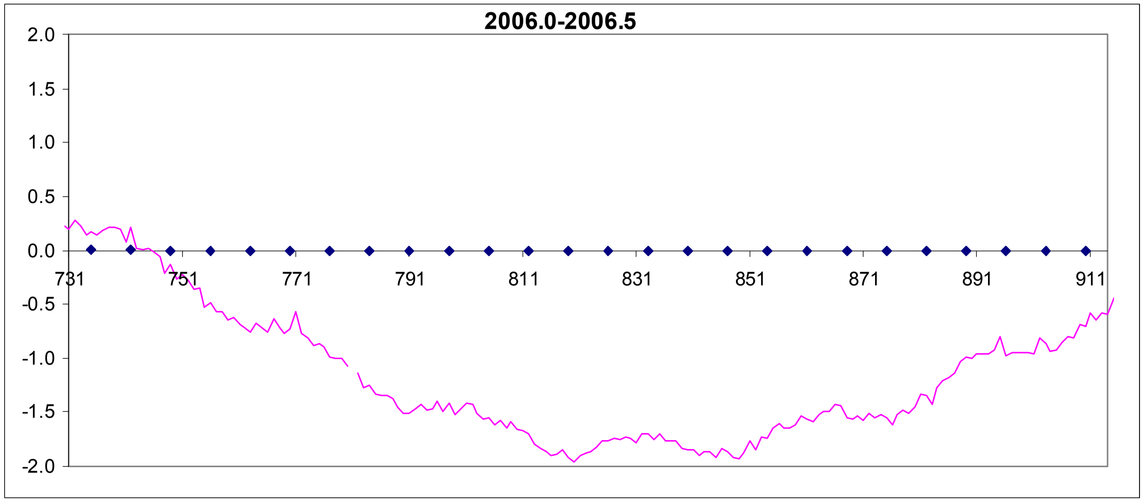
There is a phase shift of ~1 week after the perihelion/aphelion times that is a mystery:



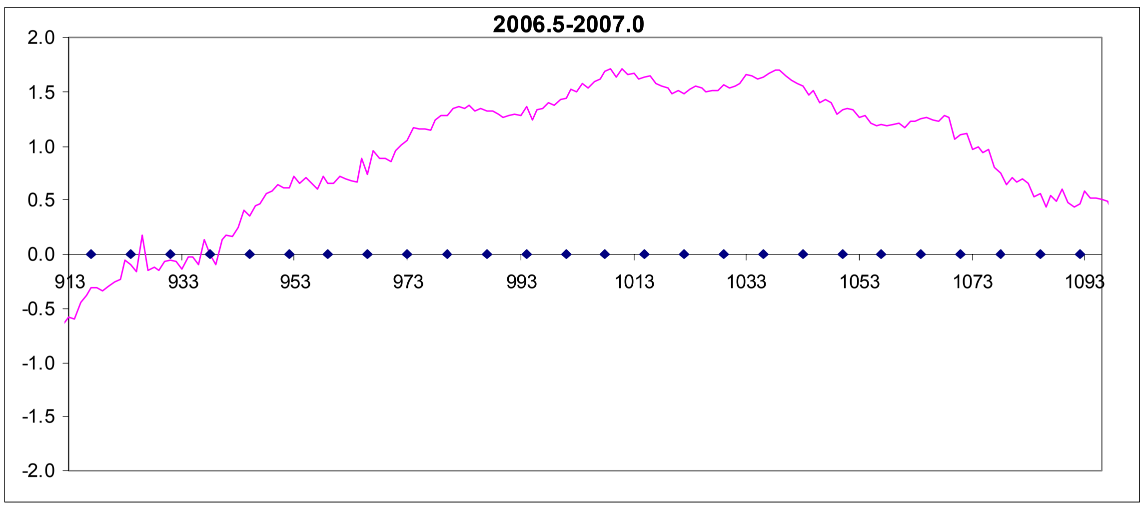



2005.0-2005.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
365
385
405
425
445
465
485
505
525
545

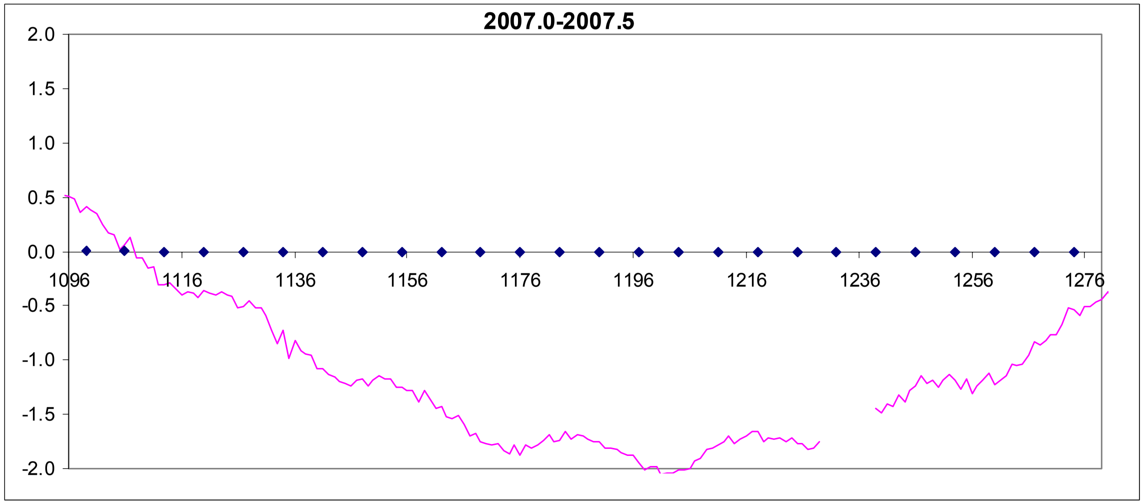

2005.5-2006.0
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
548
568
588
608
628
648
668
688
708
728

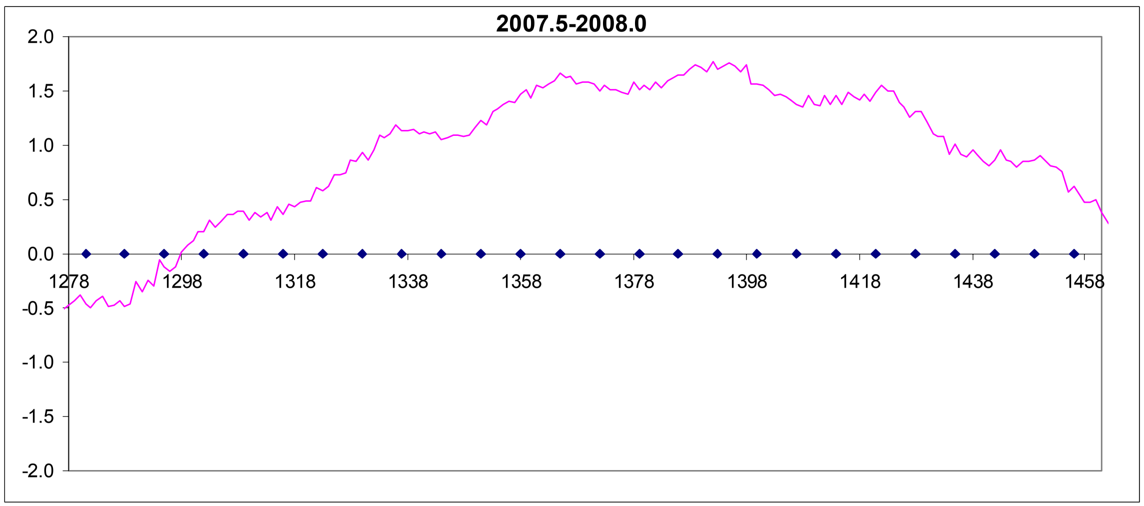


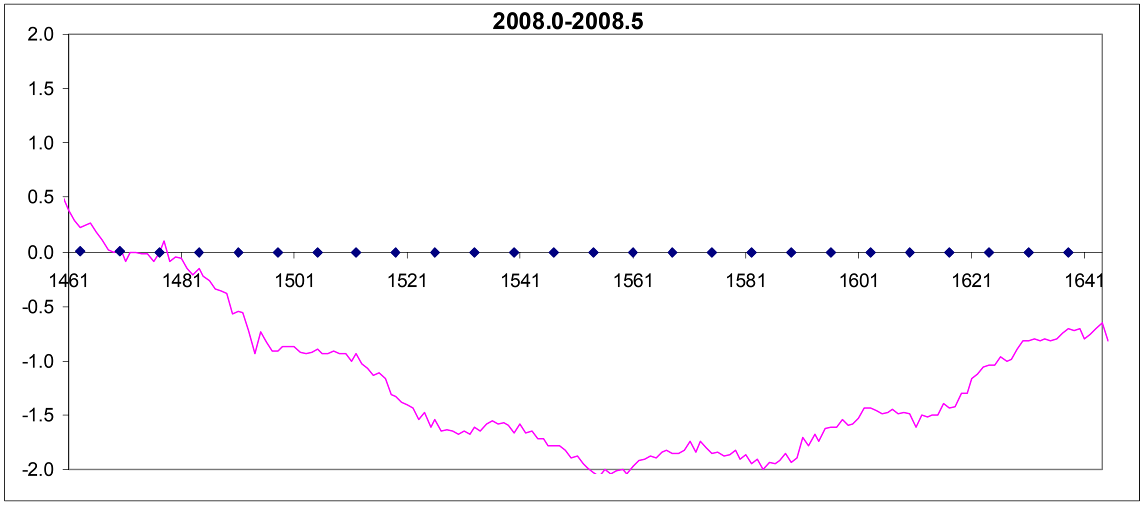
2006.0-2006.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
731
751
771
791
811
831
851
871
891
911

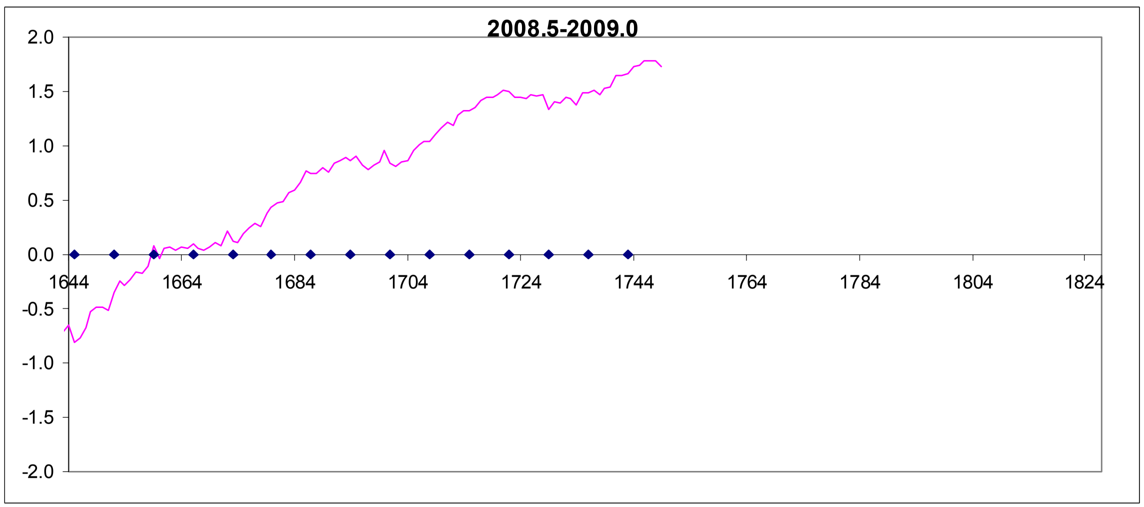


2006.5-2007.0
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
913
933
953
973
993
1013
1033
1053
1073
1093


2007.0-2007.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1096
1116
1136
1156
1176
1196
1216
1236
1256
1276


2007.5-2008.0
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1278
1298
1318
1338
1358
1378
1398
1418
1438
1458


2008.0-2008.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1461
1481
1501
1521
1541
1561
1581
1601
1621
1641


2008.5-2009.0
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1644
1664
1684
1704
1724
1744
1764
1784
1804
1824

The ‘4-minute Correction’

Leif Svalgaard 11/7/2008

It was suggested that the distance to the Sun should be calculated 8 minutes before the time of observation. Figure 1 shows the G-function for the distance calculated at the time of observation. There is clearly an annual variation, which was surmised to be corrected by calculating the distance at a time Δt = 1AU/c before the observation. Figure 2 shows the G-function with Δt = 8 minutes. There is clearly still an annual variation, but with opposite sign. This suggests using half of 8 minutes as Δt. This time we are a bit more precise and use Δt = 4:09.5 minutes. The result is Figure 3. The remaining annual variation has now a different phase [keyed on perihelion and aphelion]. This is to be expected because Δt really varies between 4:05.3 minutes and 4:13.7 minutes on account of the eccentricity of the orbit. The lunar variation is now very prominent.

I suggest using half of the true [varying through the year] light flight time as Δt. Now, does this make sense? It does remove the 1.6 ppm annual variation that I argued was in the observed TSI.

Note that the ‘phase shift’ has also been resolved.

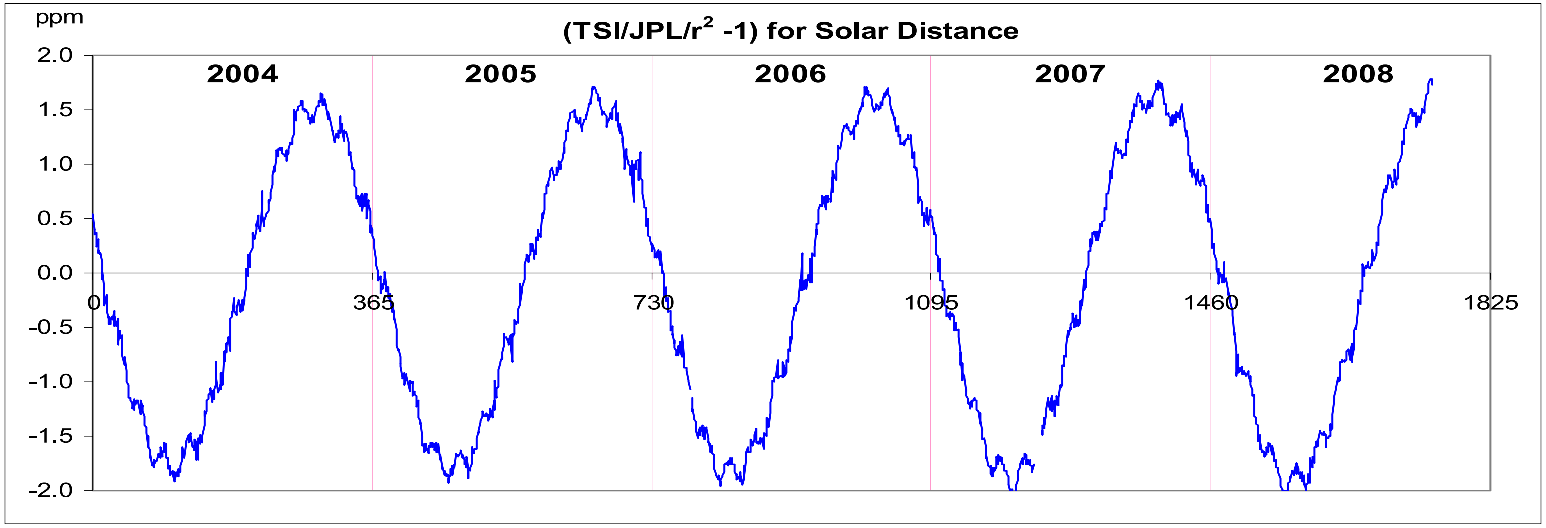


Figure 1

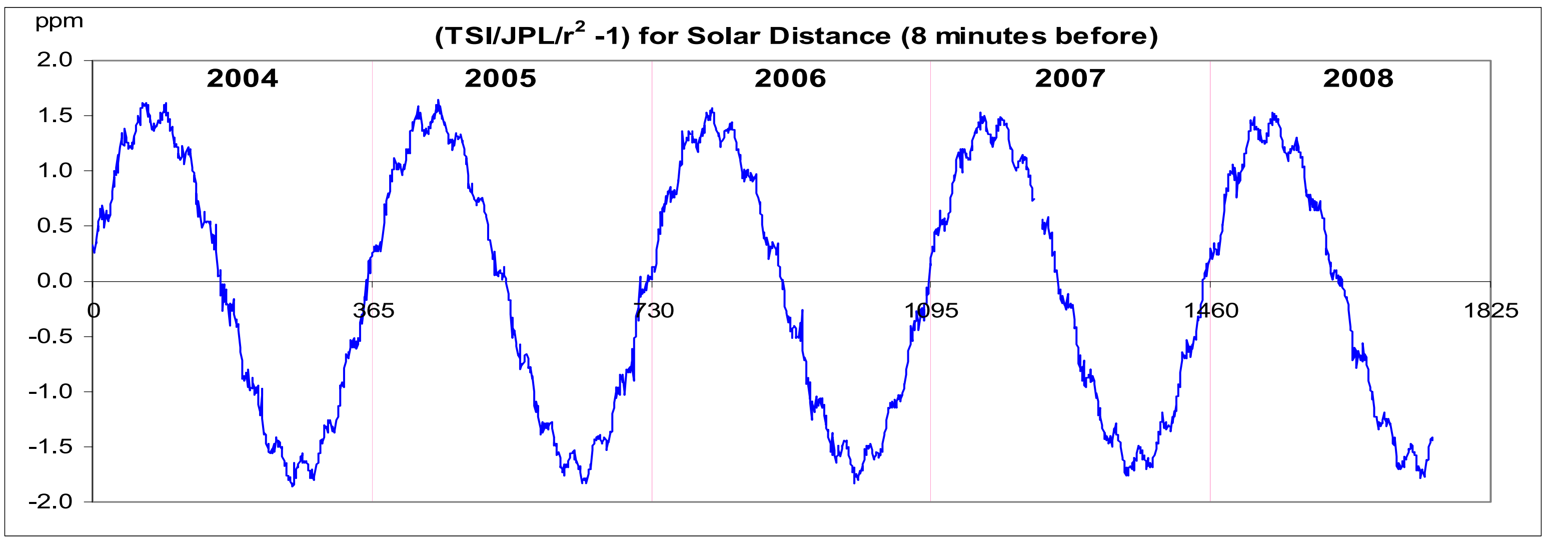


Figure 2

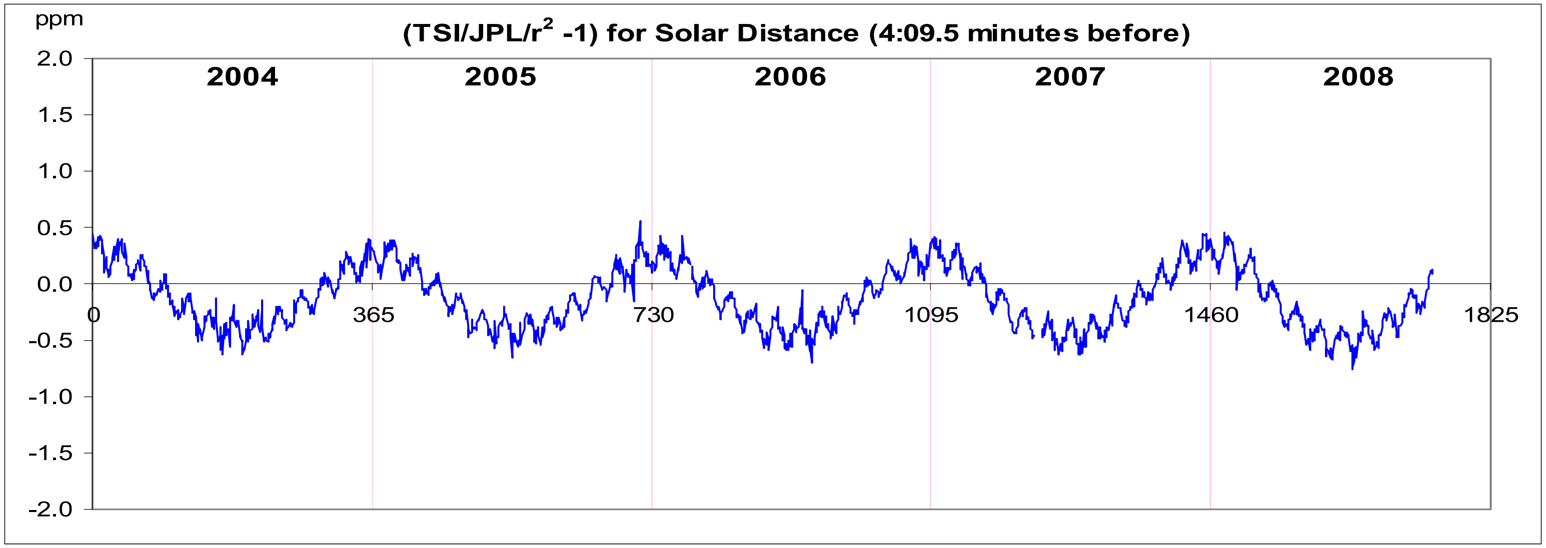


Figure 3

The asymmetry [average is -0.1] may be caused by the fact that the Earth's [radial] speed is not symmetric either.

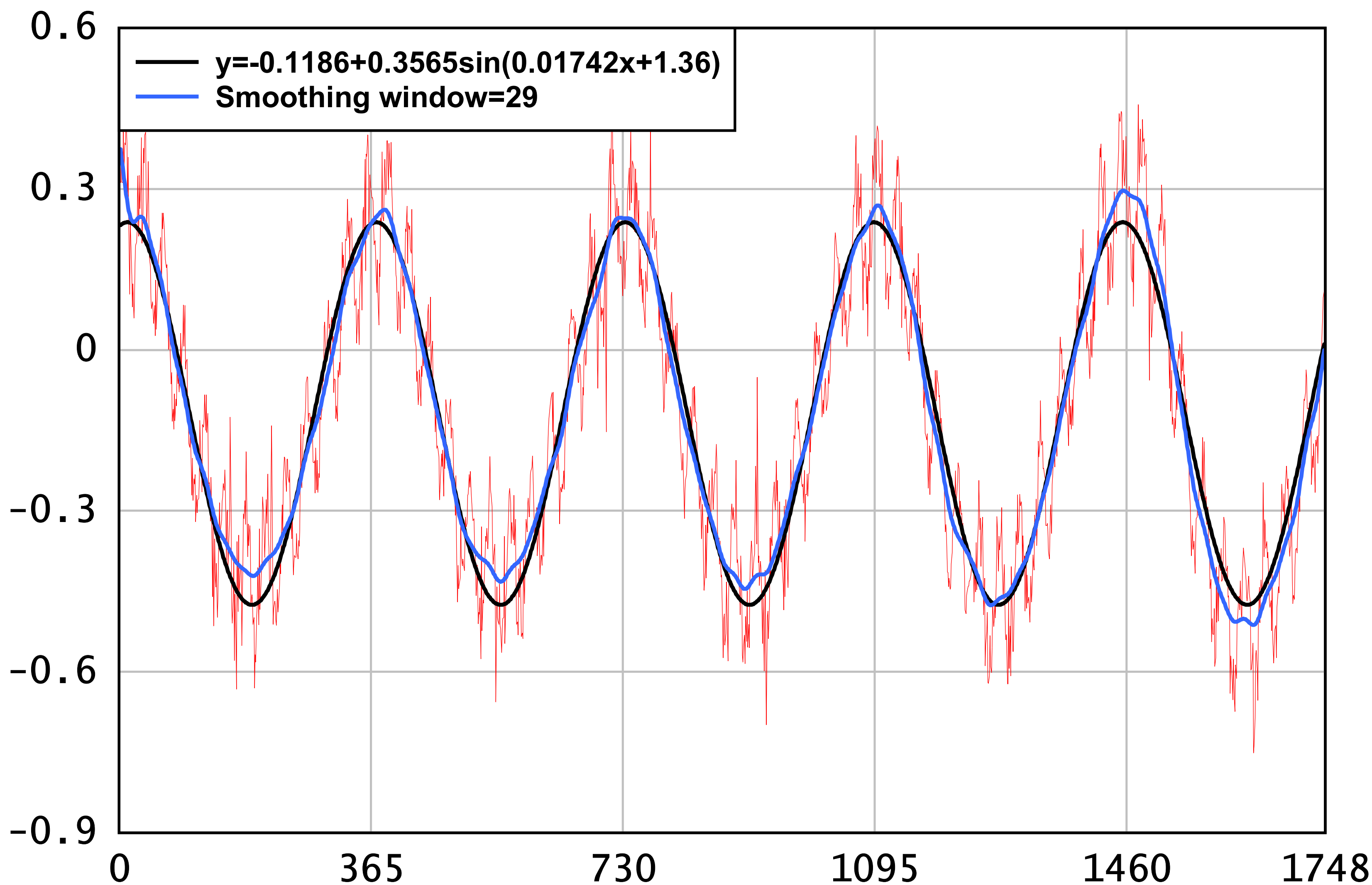

y=-0.1186+0.3565sin(0.01742x+1.36)
Smoothing window=29
0.6
0.3
0
-0.3
-0.6
-0.9
0
365
730
1095
1460
1748

Figure 4