

Ulysses' Position Angle During the Winter 2007 and Winter 2008 Extended SOHO-Sun-Ulysses Quadratures

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These notes contain the following:

1. A brief description of the Ulysses orbit
2. A brief description of SOHO-Sun-Ulysses quadratures
3. A detailed description of the two extended quadratures in winters 2007 and 2008
4. Detailed description and a plot of the Ulysses position angle (PA) in winters 2007-2008
5. An Appendix showing tabular data on the Ulysses PA

If you don't need all the background information, then you can just refer to Figures 4 and 5 and the Appendix.

1. The Ulysses Orbit

Ulysses is in a solar polar orbit of inclination 80.2° , perihelion 1.34 AU, aphelion 5.4 AU, and period 6.2 years (Fig. 1). Fig. 2 contains a plot of the orbital radius and heliographic latitude, along with a plot of the sunspot number since launch.

The orbit is highly elliptic. Considering the time between north and south polar passages, Ulysses spends about five times as long in the aphelion portion of the orbit than in the perihelion portion of the orbit. For this reason, the south-to-north passage containing the perihelion is called the 'fast latitude scan,' while the north-to-south passage containing the aphelion is called the 'slow latitude scan.' The slow latitude scan takes ~ 5.4 years and the fast latitude scan (FLS) takes ~ 1 year. In Fig. 2, the three Ulysses' orbits and the three fast latitude scans are labeled (O-I, -II, -III; FLS I, II, III).

2. SOHO-Sun-Ulysses Quadratures

Fig. 1 also shows the orbit of the Earth. For all practical purposes, SOHO is at the same location as Earth on this scale, so they will be treated so from here on. Inspecting this figure indicates that quadratures will generally occur twice each year as SOHO revolves around the Sun. This is especially true during the slow latitude scan because Ulysses is moving very slowly relative to the motion of SOHO around the Sun and therefore is essentially fixed in space.

Fig. 3 shows the SOHO-Sun-Ulysses included angle (IA) from 1 January 2001 to 1 January 2009. The general occurrence of quadratures twice per year is illustrated here. SOHO is moving around the Sun about $1^\circ/\text{day}$. Therefore, Ulysses is normally within $\pm 7^\circ$ of the limb for a period of two weeks centered on the quadrature date and time. 7° is close enough to the limb to expect that Ulysses will often sample activity on the limb. Feature tracking of phenomena rotating past the limb can be used to accurately refine the relationship between activity and phenomena near the limb and what is detected at Ulysses. It is important to realize that the Sun is rotating during a two week interval. During such an interval the Sun will rotate through $\sim 180^\circ$.

There are two times in Fig. 3 when quadratures do not occur twice per year. The first in 2001 when the second quadrature never actually quite occurred because the IA never reached 90° . The second is in 2006-2007 and 2007-2008. In these cases, two quadratures have effectively merged. The IA lingers near 90° for extended intervals. The first of these unusual times was in FLS II and the second and third are in FLS III. FLSs are when Ulysses can no longer be considered to

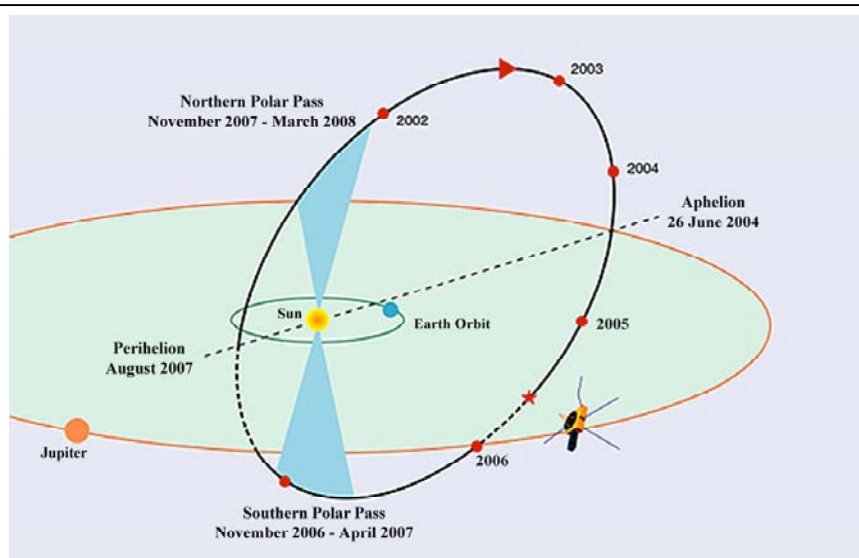


Figure 1. Ulysses' orbit, 2002-2008.

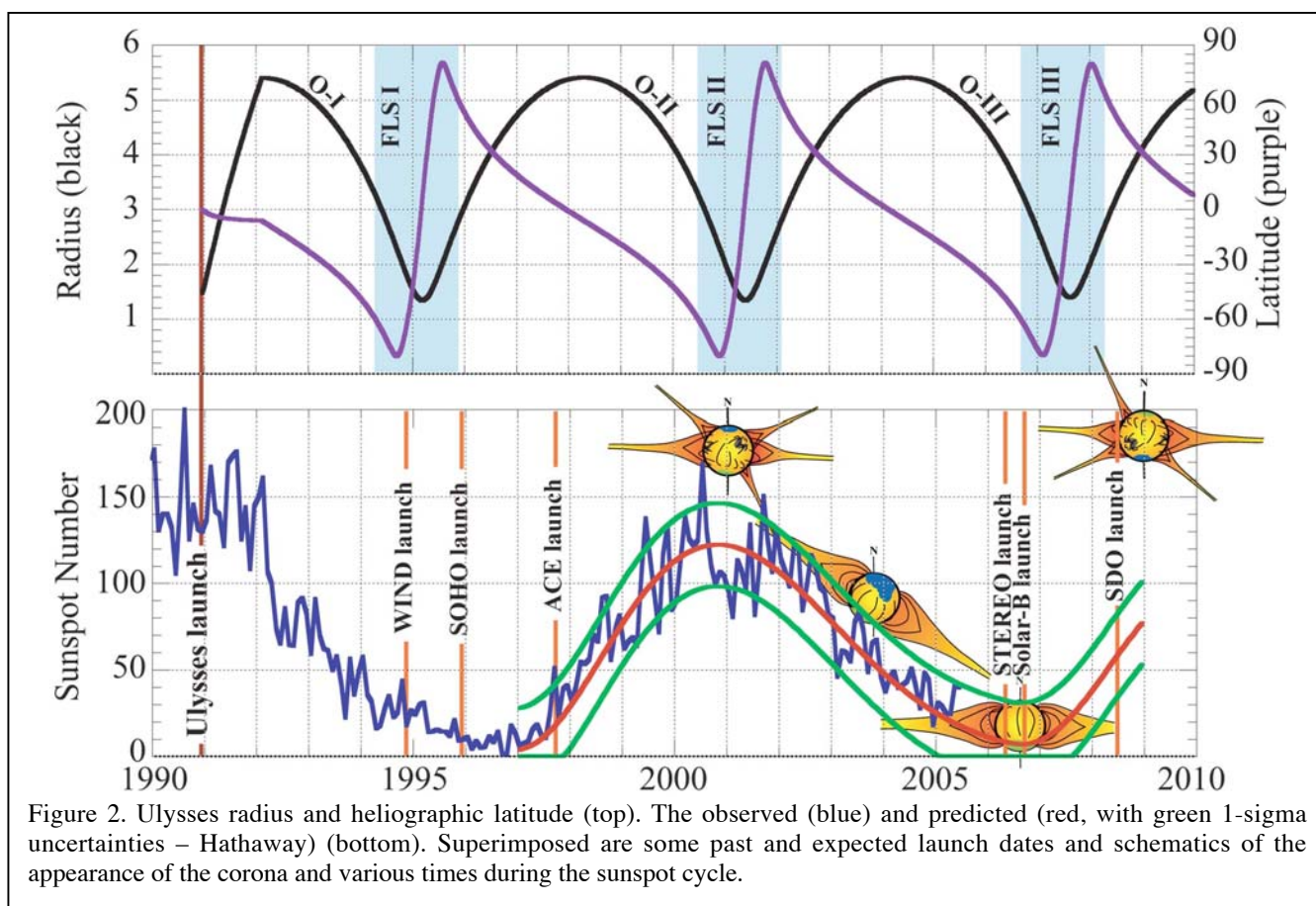
be moving slowly, causing the unusual behavior in the IA. The 2001 case worked against quadrature observations. The 2006-2008 cases work in favor of quadrature observations.

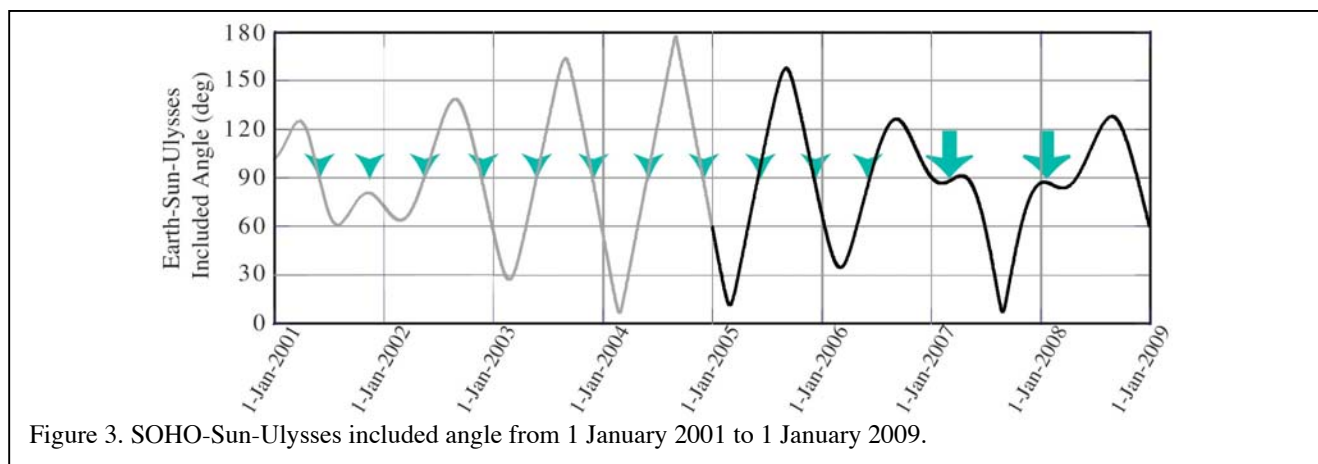
3. The Winter 2007 & Winter 2008 Extended Quadratures

The first of these two quadratures (referred to from here on as the W2007 and W2008) starts as Ulysses is at 74.4° S and approaching its maximum southern latitude and continues until Ulysses moves back down to $\sim 52.8^\circ$ S off the west limb. The dates are 19 December 2006 to 19 May 2007. The distance to Ulysses begins as 2.72 AU and decreases to 1.72 AU. Typically, it will take one to two weeks for the solar wind to reach Ulysses at these distances. This lag must be taken in to account when comparing solar phenomena to Ulysses data. Ulysses will be within $\pm 5^\circ$ of the limb over this entire interval.

W2008 is much the same as W2007, except that it occurs after Ulysses has passed its perihelion and has begun moving back away from the Sun over the north pole. W2008 begins on 2 December 2007 and lasts until 28 May 2008, while Ulysses moves from 69.8° N to its maximum northern latitude and then back down to 56.8° N. The distance to Ulysses varies from 1.79 AU out to 2.96 AU. Conditions are not quite so ideal during W2008, with Ulysses only being within $\pm 10^\circ$ of the limb over this interval.

It is a little difficult to visualize the motion of Ulysses in W2007 and W2008. To help, views of the Ulysses orbit in a frame of reference fixed in the Earth(SOHO)-Sun frame of reference are shown in Fig. 4. The left panel shows the orbit viewed from east of the SOHO-Sun line, the center panel is the view from behind SOHO looking towards the Sun, and the third panel is the view from heliographic north. The red star is just a marker for the near-radial alignment of Ulysses with near-Earth spacecraft as it passes the plane of the ecliptic in summer 2007. This is of interest for energetic particle transport studies. In these three panels, the arrow shows the motion of Ulysses, the maroon portion shows W2007, and the green portion shows W2008. The axes are in AU.





Ulysses' Position Angle (PA) During the Winter 2007 and Winter 2008 Quadratures

The PA is computed as the angle, moving counter-clockwise, from heliographic north. Its variation throughout W2007 and W2008 is shown in Fig. 5, along with IA and the heliocentric distance to Ulysses. In this plot, the date is given across the bottom and the fractional day of year (DoY) is shown across the top. The dates are for 12:00:00 on each day. The DoY is shown to four decimal places and is accurate to this value. It is probably more accurate than using the dates across the bottom. The dates can be a little off because of the plotting software (Kaleidagraph).

A tabular listing of the PA, along with date (centered on noon), fractional day of year, IA, and radius to Ulysses is in the Appendix. These are given at 4-day intervals. A simple linear extrapolation between these values gives more accuracy than generally required for extrapolations to Ulysses.

If you need help with figuring out when the plasma should reach Ulysses, we will be glad to help. Probably it is best to contact:

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Ulysses data is easily accessed at NSSDC and through the Ulysses Data System (UDS). Web sites are:

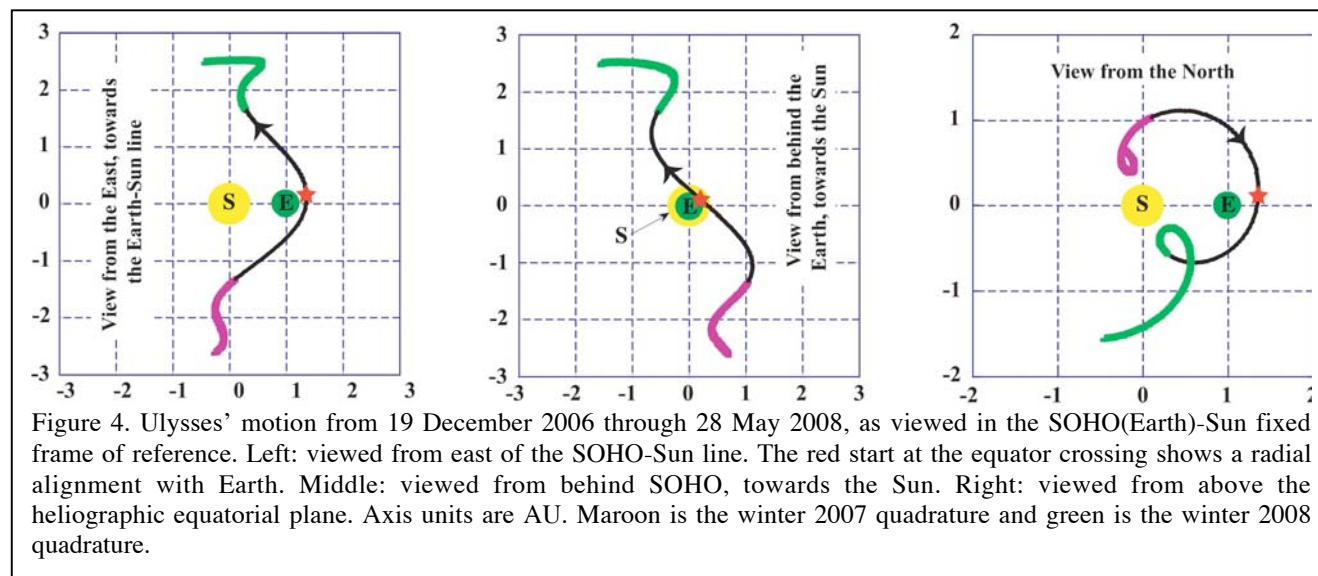
(UDS) http://helio.esa.int/ulysses/data_archive.html

(UDS mirror) http://ulysses-ops.jpl.esa.int/ulysses/data_archive.html

(NSSDC) <http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1990-090B>

Typical solar wind parameters that are available from the SWOOPS instrument include solar wind proton and electron densities, flow speeds, and temperatures. The vector magnetic field is available at a higher cadence than the plasma. Solar wind composition and ionization state data is available from the SWICS instrument. There is a large amount of energetic particle and radio data.

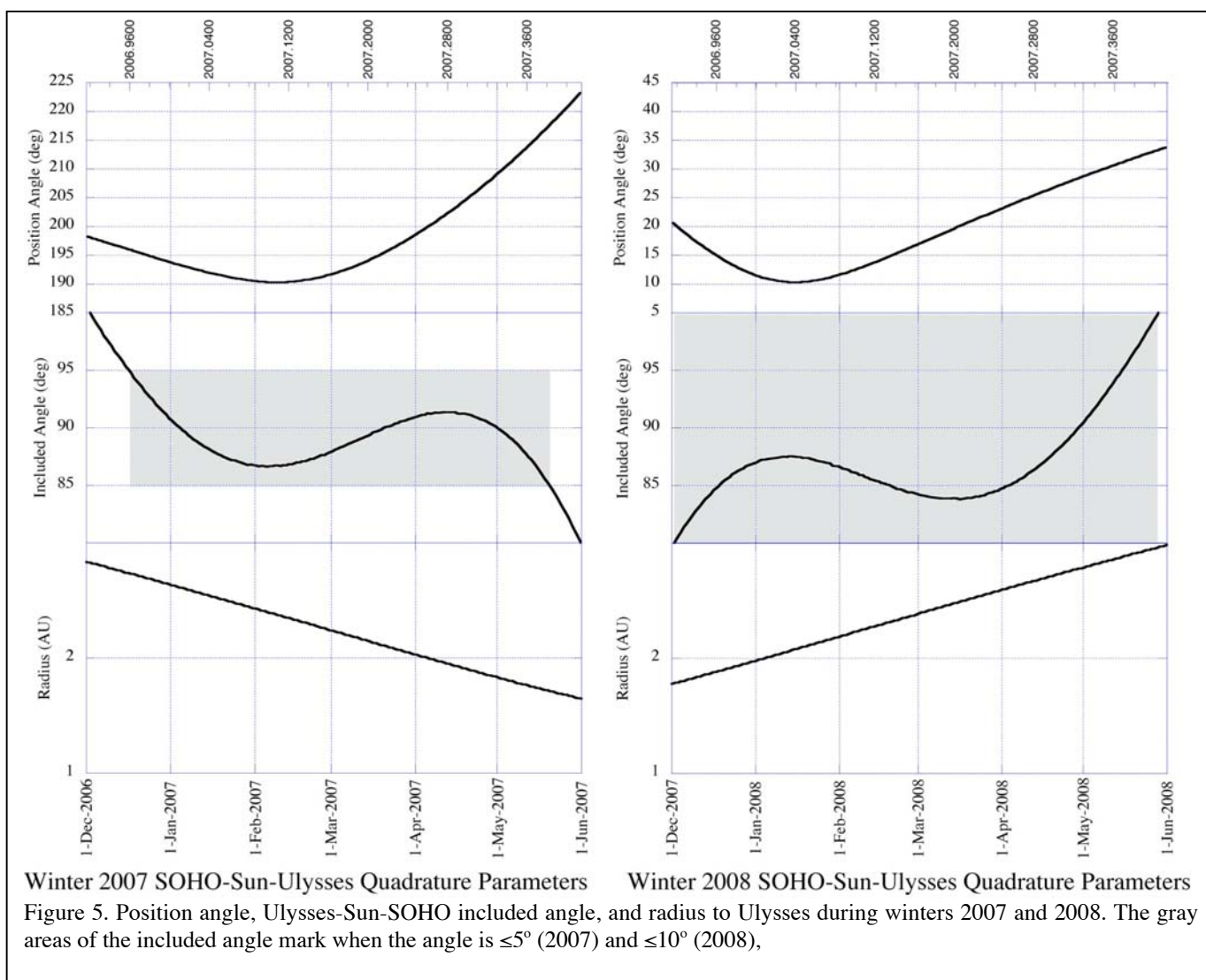
The figures in this pdf manuscript are all jpegs because that seemed to work best with Word. However, if you want an eps file of any figure so that you can scale it (except figure 1, for which there is only a jpeg), then let us know and we'll send



it to you.

A final note:

Ulysses is presently scheduled for shut-off on 1 April 2008. This is before the end of W2008. I will make an effort to keep the mission running through the end of May 2008. There are technical issues with continuing operations past 1 April, but it is not hopeless. - SS



5. Appendix: Ulysses' orbital parameters during the winter 2007 and winter 2008 extended quadratures.

| Winter 2007 | | | | | Winter 2008 | | | | | | |
|-------------|-------------|--------|----------|-----------|---------------|------------|-------------|--------|----------|-----------|---------------|
| Frac. Year | Date | Radius | Latitude | Incl.Ang. | PositionAngle | Frac. Year | Date | Radius | Latitude | Incl.Ang. | PositionAngle |
| 2006.9164 | 01-Dec-2006 | 2.8300 | -71.800 | 100.29 | 198.20 | 2007.9164 | 01-Dec-2007 | 1.7800 | 69.400 | 79.860 | 20.600 |
| 2006.9247 | 04-Dec-2006 | 2.8200 | -72.200 | 99.166 | 197.80 | 2007.9274 | 05-Dec-2007 | 1.8000 | 71.000 | 81.383 | 19.000 |
| 2006.9274 | 05-Dec-2006 | 2.8100 | -72.400 | 98.815 | 197.60 | 2007.9384 | 09-Dec-2007 | 1.8300 | 72.400 | 82.644 | 17.600 |
| 2006.9384 | 09-Dec-2006 | 2.7800 | -73.000 | 97.373 | 197.00 | 2007.9493 | 13-Dec-2007 | 1.8600 | 73.800 | 83.809 | 16.200 |
| 2006.9493 | 13-Dec-2006 | 2.7600 | -73.500 | 96.080 | 196.50 | 2007.9603 | 17-Dec-2007 | 1.8800 | 75.000 | 84.766 | 15.000 |
| 2006.9603 | 17-Dec-2006 | 2.7300 | -74.100 | 94.801 | 195.90 | 2007.9712 | 21-Dec-2007 | 1.9100 | 76.200 | 85.603 | 13.800 |
| 2006.9712 | 21-Dec-2006 | 2.7100 | -74.700 | 93.554 | 195.30 | 2007.9822 | 25-Dec-2007 | 1.9300 | 77.200 | 86.266 | 12.800 |
| 2006.9822 | 25-Dec-2006 | 2.6800 | -75.300 | 92.436 | 194.70 | 2007.9932 | 29-Dec-2007 | 1.9600 | 78.000 | 86.753 | 12.000 |
| 2006.9932 | 29-Dec-2006 | 2.6500 | -75.900 | 91.370 | 194.10 | 2008.0042 | 02-Jan-2008 | 1.9900 | 78.700 | 87.163 | 11.300 |
| 2007.0042 | 02-Jan-2007 | 2.6300 | -76.500 | 90.399 | 193.50 | 2008.0150 | 06-Jan-2008 | 2.0100 | 79.200 | 87.319 | 10.800 |
| 2007.0150 | 06-Jan-2007 | 2.6000 | -77.000 | 89.617 | 193.00 | 2008.0260 | 10-Jan-2008 | 2.0400 | 79.500 | 87.473 | 10.500 |
| 2007.0260 | 10-Jan-2007 | 2.5700 | -77.500 | 88.839 | 192.50 | 2008.0369 | 14-Jan-2008 | 2.0700 | 79.700 | 87.516 | 10.300 |
| 2007.0370 | 14-Jan-2007 | 2.5500 | -78.000 | 88.230 | 192.00 | 2008.0479 | 18-Jan-2008 | 2.1000 | 79.600 | 87.376 | 10.400 |
| 2007.0480 | 18-Jan-2007 | 2.5200 | -78.400 | 87.709 | 191.60 | 2008.0587 | 22-Jan-2008 | 2.1200 | 79.400 | 87.242 | 10.600 |
| 2007.0590 | 22-Jan-2007 | 2.4900 | -78.800 | 87.266 | 191.20 | 2008.0697 | 26-Jan-2008 | 2.1500 | 79.100 | 87.010 | 10.900 |
| 2007.0698 | 26-Jan-2007 | 2.4700 | -79.100 | 87.032 | 190.90 | 2008.0806 | 30-Jan-2008 | 2.1800 | 78.600 | 86.676 | 11.400 |
| 2007.0808 | 30-Jan-2007 | 2.4400 | -79.400 | 86.826 | 190.60 | 2008.0916 | 03-Feb-2008 | 2.2000 | 78.100 | 86.415 | 11.900 |
| 2007.0918 | 03-Feb-2007 | 2.4100 | -79.600 | 86.706 | 190.40 | 2008.1024 | 07-Feb-2008 | 2.2300 | 77.400 | 86.068 | 12.600 |
| 2007.1028 | 07-Feb-2007 | 2.3900 | -79.700 | 86.657 | 190.30 | 2008.1134 | 11-Feb-2008 | 2.2600 | 76.700 | 85.679 | 13.300 |
| 2007.1136 | 11-Feb-2007 | 2.3600 | -79.700 | 86.765 | 190.30 | 2008.1243 | 15-Feb-2008 | 2.2900 | 76.000 | 85.358 | 14.000 |
| 2007.1246 | 15-Feb-2007 | 2.3300 | -79.600 | 86.906 | 190.40 | 2008.1353 | 19-Feb-2008 | 2.3100 | 75.200 | 85.037 | 14.800 |
| 2007.1356 | 19-Feb-2007 | 2.3100 | -79.300 | 87.110 | 190.70 | 2008.1461 | 23-Feb-2008 | 2.3400 | 74.400 | 84.683 | 15.600 |
| 2007.1466 | 23-Feb-2007 | 2.2800 | -79.000 | 87.408 | 191.00 | 2008.1571 | 27-Feb-2008 | 2.3700 | 73.600 | 84.407 | 16.400 |
| 2007.1576 | 27-Feb-2007 | 2.2500 | -78.500 | 87.770 | 191.50 | 2008.1626 | 29-Feb-2008 | 2.3800 | 73.200 | 84.261 | 16.800 |
| 2007.1685 | 03-Mar-2007 | 2.2200 | -78.000 | 88.175 | 192.00 | 2008.1708 | 03-Mar-2008 | 2.4000 | 72.600 | 84.091 | 17.400 |
| 2007.1794 | 07-Mar-2007 | 2.2000 | -77.300 | 88.610 | 192.70 | 2008.1816 | 07-Mar-2008 | 2.4300 | 71.800 | 83.932 | 18.200 |
| 2007.1904 | 11-Mar-2007 | 2.1700 | -76.600 | 89.015 | 193.40 | 2008.1926 | 11-Mar-2008 | 2.4600 | 71.000 | 83.876 | 19.000 |
| 2007.2014 | 15-Mar-2007 | 2.1400 | -75.700 | 89.416 | 194.30 | 2008.2035 | 15-Mar-2008 | 2.4800 | 70.100 | 83.869 | 19.900 |
| 2007.2123 | 19-Mar-2007 | 2.1100 | -74.800 | 89.841 | 195.20 | 2008.2145 | 19-Mar-2008 | 2.5100 | 69.300 | 83.938 | 20.700 |
| 2007.2233 | 23-Mar-2007 | 2.0900 | -73.800 | 90.225 | 196.20 | 2008.2255 | 23-Mar-2008 | 2.5400 | 68.500 | 84.023 | 21.500 |
| 2007.2343 | 27-Mar-2007 | 2.0600 | -72.800 | 90.603 | 197.20 | 2008.2363 | 27-Mar-2008 | 2.5600 | 67.800 | 84.345 | 22.200 |
| 2007.2452 | 31-Mar-2007 | 2.0300 | -71.600 | 90.915 | 198.40 | 2008.2473 | 31-Mar-2008 | 2.5900 | 67.000 | 84.700 | 23.000 |
| 2007.2561 | 04-Apr-2007 | 2.0100 | -70.400 | 91.138 | 199.60 | 2008.2582 | 04-Apr-2008 | 2.6200 | 66.200 | 85.064 | 23.800 |
| 2007.2671 | 08-Apr-2007 | 1.9800 | -69.200 | 91.327 | 200.80 | 2008.2692 | 08-Apr-2008 | 2.6400 | 65.400 | 85.621 | 24.600 |
| 2007.2781 | 12-Apr-2007 | 1.9500 | -67.800 | 91.344 | 202.20 | 2008.2800 | 12-Apr-2008 | 2.6700 | 64.700 | 86.304 | 25.300 |
| 2007.2891 | 16-Apr-2007 | 1.9300 | -66.500 | 91.254 | 203.50 | 2008.2910 | 16-Apr-2008 | 2.6900 | 63.900 | 87.010 | 26.100 |
| 2007.3000 | 20-Apr-2007 | 1.9000 | -65.000 | 91.168 | 205.00 | 2008.3019 | 20-Apr-2008 | 2.7200 | 63.200 | 87.889 | 26.800 |
| 2007.3109 | 24-Apr-2007 | 1.8700 | -63.500 | 90.786 | 206.50 | 2008.3129 | 24-Apr-2008 | 2.7500 | 62.500 | 88.771 | 27.500 |
| 2007.3219 | 28-Apr-2007 | 1.8500 | -62.000 | 90.364 | 208.00 | 2008.3237 | 28-Apr-2008 | 2.7700 | 61.800 | 89.791 | 28.200 |
| 2007.3329 | 02-May-2007 | 1.8200 | -60.300 | 89.745 | 209.70 | 2008.3347 | 02-May-2008 | 2.8000 | 61.100 | 90.900 | 28.900 |
| 2007.3439 | 06-May-2007 | 1.8000 | -58.700 | 89.016 | 211.30 | 2008.3456 | 06-May-2008 | 2.8200 | 60.400 | 92.044 | 29.600 |
| 2007.3547 | 10-May-2007 | 1.7700 | -56.900 | 88.000 | 213.10 | 2008.3566 | 10-May-2008 | 2.8500 | 59.700 | 93.368 | 30.300 |
| 2007.3657 | 14-May-2007 | 1.7500 | -55.100 | 86.960 | 214.90 | 2008.3674 | 14-May-2008 | 2.8700 | 59.000 | 94.631 | 31.000 |
| 2007.3767 | 18-May-2007 | 1.7200 | -53.300 | 85.566 | 216.70 | 2008.3784 | 18-May-2008 | 2.9000 | 58.400 | 96.093 | 31.600 |
| 2007.3877 | 22-May-2007 | 1.7000 | -51.400 | 84.151 | 218.60 | 2008.3894 | 22-May-2008 | 2.9200 | 57.700 | 97.539 | 32.300 |
| 2007.3987 | 26-May-2007 | 1.6800 | -49.400 | 82.507 | 220.60 | 2008.4003 | 26-May-2008 | 2.9500 | 57.100 | 99.109 | 32.900 |
| 2007.4095 | 30-May-2007 | 1.6500 | -47.300 | 80.616 | 222.70 | 2008.4113 | 30-May-2008 | 2.9700 | 56.400 | 100.66 | 33.600 |