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Venus Gravity Handbook

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Abstract

This report documents the Venus gravity methods and results to date (model MGNP90LSAAP). It is called a handbook in that it contains many useful plots (such as geometry and orbit behavior) that are useful in evaluating the tracking data. We discuss the models that are used in processing the Doppler data and the estimation method for determining the gravity field. With Pioneer Venus Orbiter and Magellan tracking data, the Venus gravity field was determined complete to degree and order 90 with the use of the JPL Cray T3D Supercomputer. The gravity field shows unprecedented high correlation with topography and resolution of features to the 200km resolution. In the procedure for solving the gravity field, other information is gained as well, and, for example, we discuss results for the Venus ephemeris, Love number, pole orientation of Venus, and atmospheric densities. Of significance is the Love number solution which indicates a liquid core for Venus. The ephemeris of Venus is determined to an accuracy of 0.02 mm/s (tens of meters in position), and the rotation period to 243.0194±0.0002 days.

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1. Introduction

Two spacecraft orbiters, Magellan and Pioneer Venus Orbiter (Pioneer 12 or PVO), provide nearly a global gravity data set for Venus. Together they have been used to solve for a 90th degree and order spherical harmonic gravity field of Venus as well as the GM of Venus (gravitational constant times the mass), ephemeris of Venus with respect to the Earth, tide or Love number (k_2) of Venus, pole and rotation rate of Venus, and other addition models such as atmospheric densities and Venus albedo variations. This handbook documents the data used in the reduction and presents the results to date.

Prior to Magellan and PVO, the Mariner 2, 5, and 10 flybys of Venus provided mass estimates and an upper bound on J_2 (Anderson and Efron, 1969 and Howard et al , 1974) showing that the oblateness for Venus was several orders of magnitude smaller than the Earth's oblateness. The Russian Venera 9 and 10 spacecraft provided a more accurate estimate of $J_2 = 4.0 \pm 1.5 \times 10^{-6}$ (Akim et al, 1978). The initial spherical harmonic determinations of the Venus gravity field from PVO were low degree and order solutions by Ananda et al (1980) to degree and order six and Williams et al (1983) to degree and order seven. Mottinger et al (1985) extended the harmonic solution to degree and order ten by using only high-altitude periapse (about 1000 km) data from PVO, and Bills et al (1987) solved for a degree and order 18 field by combining the high-altitude data with low-altitude data arcs. In addition to harmonic analyses, others such as Phillips et al (1979), Sjogren et al (1980, 1983, 1984), Reasenberg et al (1981, 1982), and more recently Reasenberg and Goldberg (1992) have solved for high resolution surface mass distributions either regionally or globally.

With the arrival of faster computers with more memory and disk space, the spherical harmonic solutions have shown a drastic increase in resolution. In support of the Magellan Navigation effort, McNamee et al (1992) reprocessed the low-altitude PVO data to produce a 21st degree and order model. Nerem (1991) with the additional high-altitude PVO data set produced the Preliminary Goddard Venus Model 1, a 36th degree and order field, and ushered in dramatic increases in resolution for harmonic fields. Konopliv (1992) followed with a 42nd degree and order field and Nerem et al (1993) with a 50th degree and order field, all based upon PVO low- and high-altitude data sets.

With Magellan now in orbit, McNamee et al (1993) produced another 21st degree and order field incorporating Magellan high-altitude (periapse altitude of 250 km) data with PVO. After September 1992, Magellan began to be tracked during periapse (altitude of 170 km). Prior to this, the high gain antenna was pointed toward Venus to acquire Synthetic Aperture Radar (SAR) images and no Doppler tracking was obtained within 30 minutes of periapse. Konopliv et al (1993a) produced a 60th degree and order model by combining the PVO data with four months (or about one-half of longitude coverage) of Magellan data. After Magellan successfully aerobraked into a near circular orbit in August of 1993, Konopliv and Sjogren (1994a) produced another 60th degree and order model incorporating much of the near circular orbit data, and Konopliv et al (1994b) produced a 75th degree and order model with all the Magellan gravity data. This report presents the results for a 90th degree and order gravity solution (named MGNP90LSAAP). This model is the highest resolution spherical harmonic model for a planet, including the Earth, that is based upon spacecraft tracking data. The current solutions for the Earth gravity field extend to degree and order 70 for solutions based upon spacecraft tracking data only (Nerem et al, 1994) and to degree and order 360 with surface measurements included (Rapp et al, 1991). Nerem et al (1995) summarize the history of gravity determination.

In addition to the spherical harmonic gravity field, line-of-sight (LOS) accelerations with respect to a spherical harmonic gravity field (degree and order 75, JPL solution MGNP75ISAAP, for the pre-aerobraking data and degree and order 40, JPL gravity solution MGN40E, for the post-aerobraking data) have been produced for the Magellan Doppler residuals. The procedure is to solve for the spacecraft state and other spacecraft specific dynamical models using the base spherical harmonic model. The residuals then contain the remaining gravity signature in the data that is not incorporated into the harmonic field. Orbits are processed one at a time, and so this eliminates long-term modeling errors (and long-term gravity information). The pre-aerobraking LOS data were processed by Barriot and Balmino (1994) to produce detailed gravity maps over Eistla Regio and the western portion of Aphrodite Terra. Kaula (1995), Smrekar (1994), and others have produced regional gravity determinations from the LOS data as well.

2. Spacecraft Tracking

The gravity measurements used for Venus gravity field determination are two-way coherent Doppler tracking of the PVO and Magellan spacecraft acquired at the Deep Space Network (DSN) complexes at Goldstone, California; Madrid, Spain; and Canberra, Australia. The PVO spacecraft operated at S-band with the DSN stations transmitting at 2.11 GHz. The transponder on board the spacecraft then multiplied the frequency by 240/221 to obtain a downlink frequency of 2.30 GHz. For PVO, only two-way data were acquired, i.e., the receiving DSN station is the same as the transmitting station. The spacecraft transponder also provided a minimal amount of X-band downlink data (S-band and X-band were received simultaneously at the ground station), but these data were not processed. The Magellan spacecraft had an S-band transponder with an X to S-band uplink converter and S to X-band downlink converter. The resulting system had either an X-band or S-band uplink and an S-band and/or X-band downlink. The X-band uplink and X-band downlink (8.43 GHz) provided the high resolution gravity data because of reduced charged particle effects on the X-band signal. All two-way Magellan data were processed beginning with the gravity data of cycle four. Three-way data (i.e., the receiving DSN complex is different from the transmitting complex) were also taken for generation of differenced Doppler data in support of navigation, but these data were not incorporated into the gravity solution.

PVO was inserted into orbit about Venus on December 4, 1978 and provided several years of low-altitude periapse data (150 to 170 km) until July of 1980 when no maneuvers were performed to maintain a low periapse altitude. By November of 1980, periapse altitude reached 400 km due to solar perturbations on the orbit. The low-altitude data set is continuous from December 9, 1978 to December 4, 1980 except for a data gap from July 12, 1979 to December 18, 1979, during which superior conjunction occurred and periapse was occulted, and so these data will not add much to the gravity solution. Tracking data were acquired during this time, but these data have not been recovered from archive tapes and may or may not exist. Due to the superior resolution of the Magellan data, the PVO data were compressed substantially to 60 seconds for the interval within thirty minutes each side of periapse, 300 seconds for the next two hours around periapse, and 600 seconds near apoapse. The spacecraft velocity at periapse is 9 km/s and 60 second samples decrease the periapse resolution in the PVO data, but this is easily recovered with the Magellan data and the three to four longitudinal coverages of the PVO data. This compression time still retains the long term gravity, rotational, tidal, and ephemeris information and greatly reduces computer time required for filtering. Future solutions may reintroduce a higher number of samples at periapse. The original PVO data, as processed by Konopliv et al (1993a) and others have 5 second samples at periapse. The total number of Doppler observations processed for the low-altitude PVO data is 170,000.

The time histories of the low-altitude orbit semi-major axis, eccentricity, inclination, latitude at periapse, longitude at periapse, altitude at periapse, plane-of-sky inclination, one-way light time, Sun-Earth-Venus angle, Earth-Venus-Probe at periapse angle, and local solar time at periapse are given in Appendix A. PVO had a highly eccentric (e=0.8) orbit with a period of 24 hours and was nearly polar with an inclination of 106°. Because of the high eccentricity, the altitude climbed to over 1000 km for the high latitude regions (>60°N, <30°S) as shown by the altitude profile in Appendix A. The approximately weekly maneuvers to lower periapse altitude are clearly evident in the semi-major axis, eccentricity, and periapse altitude plots. The geometry of the orbit provides good gravity data since the plane-of-sky inclination (angle between line-of-sight and orbit plane normal) rarely fell below 20° to near face-on geometries. Initially, periapse was occulted and became visible in March of 1979. Also, as periapse rose at the end of the low-altitude data set, periapse became occulted again (as shown by the Earth-Venus-Probe at periapse angle plot in Appendix A). Since the rotational period of Venus is 243 days, the low-altitude data provide several longitudinal coverages of Venus with the high resolution data contained within a narrow latitude band around periapse. The low-altitude data set, with the exception of the first three months of data to March 1979, is identical to the data set used by McNamee et al (1993) and Nerem et al (1993).

The second PVO data set extends from November 6, 1981 to September 7, 1982. During this time, periapse increased from 980 km to 1340 km due to the solar perturbation. At the beginning of this time span, periapse was just coming out of occultation, and near the end of the high-altitude data, periapse again entered occultation in August of 1982. After 1982, periapse altitude increased unimpeded until its maximum of about 2500 km in 1986 and then it decreased until 1992. At that time, periapse raise maneuvers were performed to keep PVO from burning up in the atmosphere. However, with propellant exhausted, PVO entered too deep into the atmosphere and the DSN lost signal on Oct. 8, 1992. This data set, due to sparseness of tracking, is not included in this gravity solution. Again, future studies may include this tracking. The high-altitude PVO was tracked continuously for three days once a week for this part of the mission (Mottinger et al, 1985), and amounts to 34,000 observations with the same compression scheme as the low-altitude PVO data. This data set is identical to the high-altitude data set used by Mottinger et al (1985) and is included in the solution by Nerem et al (1993).

Appendix B shows the high PVO orbit time histories of the same variables as the low-altitude orbit (Appendix A). The nearly conservative behavior of the orbit (due to minimal atmospheric drag) is shown by the periodic motion of the osculating semi-major axis. Since drag is small, the solar pressure force and Venus albedo forces have the major effect on the Venus orbit. For this reason, the Earth-Venus-Sun angle is also given in

Appendix B to show the angle of the PVO antenna with respect to the Venus-Sun line. With ten months of data, the high-altitude orbit provides more than one full longitudinal coverage of Venus. However, the first four months of the high-altitude data were in a nearly face-on geometry.

The Magellan spacecraft was inserted into orbit about Venus on August 10, 1990. The first three cycles (one cycle is one Venus rotation period of 243 days) were dedicated to SAR imaging of the Venus surface. This required the high gain antenna to be pointed to the Venus surface within about thirty minutes of periapse passage. Thus only high-altitude tracking (>2500 km) was obtained when the high gain antenna was returned to point at Earth. These data still, however, have some long term information on the gravity field and it was used by McNamee et al (1993). The altitude of periapse for the first three cycles is 250 km and is higher than the gravity cycle four. Except for the periapse altitude, the orbit shape for cycle four is identical to the previous cycles and should contain all the gravity information that is in the previous cycles and more. In addition for the first three cycles, the modeling of the solar pressure force for a rotating antenna through periapse passage is complicated, and solar pressure is a significant force for the higher periapse due to diminished drag. For these reasons, the first three cycles of data are not included in the gravity solution.

Cycle four began on September 15, 1992 and continued to May 24, 1993. During the complete cycle, there were no periapse altitude adjustments and the altitude varied between 185 and 165 km. Magellan was tracked through periapse with a two-second sample time, but for the spherical harmonic gravity solutions, the sample time was compressed to 10 seconds. With a periapse velocity of 8.5 km/s, 10 second samples provide two or three samples per half wavelength of a 90th degree and order field. For higher solutions, we may need to increase the number of samples near periapse. There are 770,000 10-second observations (both X and S-band) for cycle four. The time histories for Magellan cycle four are given in Appendix C. The location of periapse on the nightside and dayside (see local-solar-time plot in Appendix C) is apparent in the semi-major axis decay, with a greater drag on the dayside. Initially for cycle four, periapse is just coming out of occultation and hence a near face-on condition (<20° plane-of-sky inclination) and shows degraded gravity information. At the end of the cycle, the geometry again returns to a near face-on condition, but full longitudinal coverage was obtained with periapse tracking. However, we've noticed degraded gravity information for orbits within 20° of the face-on geometry. Due to smaller eccentricity (e=0.4), the Magellan cycle 4 data are much more sensitive at the higher latitudes than the PVO data (compare altitude vs latitude plots from the appendices), but still lack the high resolution gravity information for the higher latitudes.

At the end of May, 1993, Magellan periapse was lowered deep into the atmosphere to begin aerobraking. Over the next several months to early August, the atmospheric drag on the spacecraft changed the orbit to nearly circular to provide much lower altitude gravity tracking at the higher latitudes. From August 6, 1993 (August 17 for beginning of X-band) to October 10, 1994, Magellan was tracked in this nearly circular orbit with apoapse altitude varying from 600 km to 350 km and periapse altitude from 155 km to 220 km. Appendix D gives the time histories for the post-aerobraking orbit. This includes cycle five and part of cycle six until the Magellan spacecraft was "windmilled" into the atmosphere of Venus and lost signal. Even if the spacecraft had not been deliberately terminated, Magellan would have been lost within several weeks due to degradation of the solar arrays and loss of power. It would have never been able to fill in some tracking data gaps that remain in the gravity field. The plane-of-sky inclination versus longitude in Appendix D clearly displays the coverage of the post-aerobraking data. Initially, periapse is occulted and apoapse is tracked from longitude 100°W to 60°E, then periapse becomes visible from 220°E to 90°E except for a gap due to superior conjunction. Apoapse tracking then resumes from 110°W to 130°E, and finally periapse is tracked from 60°W to 10°E for the conclusion of the mission. As a result, there is a gap between 140°E and 220°E where there is no direct low-altitude tracking for the high latitudes. This data gap especially shows up in the southern hemisphere. During cycles five and six, there are many maneuvers to adjust periapse and apoapse altitude and these are visible in the semi-major axis plot and others. The time of the maneuvers is noted on the semi-major axis plot. The same compression time of 10 seconds is used for the post-aerobraking data and amounts to 1,230,000 observations. The velocity of the Magellan spacecraft in the nearly circular orbit is about 7 km/s, providing a sample every 70 km.

The PVO and Magellan data were processed in many arcs (a data time span which is dynamically continuous) where for each arc the initial spacecraft state and other parameters are estimated (see Appendix F). The PVO data arcs were chosen to be as long as practical given the imperfect knowledge of the spacecraft non-gravitational accelerations. The arc lengths generally were shorter in regions where uncertainties in the non-gravitational accelerations (primarily those due to atmospheric drag) were highest. In addition, the data arcs did not include any propulsive maneuvers which, as mentioned above, occurred regularly on PVO from 1978 through 1982 due to solar gravitational perturbations. The arc lengths for the low-altitude PVO tracking data varied from a minimum of one day to a maximum of ten days, with six days as the typical length. The high-altitude PVO data arcs were three days in length to match the tracking schedule. For Magellan, the data arc lengths for pre- and post-aerobraking were generally one day in length with a maximum length of two days. The long term information in the gravity field can be enhanced by increasing the arc lengths if careful attention is given to the nongravitational forces acting on the spacecraft. This will be the focus of future work.

The Magellan orbits with X-band tracking provide the highest resolution gravity information for Venus. Appendix E is a summary of all the Magellan X-band tracking and lists the orbit number, tracking data file name, number of Doppler points, tracking station number, and the time for the first observation of the orbit. The name of the tracking file also indicates whether the sample time is 10 seconds or 2 seconds. The LOS accelerations for all these orbits, with respect to the gravity fields mentioned above, were delivered to the Geoscience Node, Planetary Data System (PDS), at Washington University in St. Louis (Simpson, 1995a, gives the format of the delivery). For the LOS data, the 2-second samples were used if available; this amounted to delivery of almost 6 million observations for about 4,600 orbits.

3. Models

In this section, we discuss the observable and the geometric and dynamic models that affect the processing of the Doppler observable. The geometric models include Earth platform parameters such as station positions, precession, nutation, etc., and media calibrations for the observable due to the troposphere and ionosphere of the Earth. The dynamical models affect the spacecraft motion and are included in the numerical integration of the equations of motion for the spacecraft. In addition, any dynamic parameters that are estimated require that the partial of the spacecraft state with respect to the dynamical parameter be integrated. The parameters for the planetary ephemeris are both geometric and dynamic, but the change in force on the spacecraft due to a change in Earth position relative to Venus is negligible.

3a. Observable

The DSN station transmits either an S-band or X-band signal to the spacecraft and the spacecraft multiplies the frequency by a factor depending on the band of the uplink and downlink. For two-way S-band, the multiplier is 240/221 and for two-way X-band the factor is 880/749 (Moyer, 1987, documents the formulation for the X-Band Observable). The signal is then received at the DSN and the phase difference between the received and transmitted signal is measured with a Doppler cycle counter. The Doppler counter outputs the phase difference at integral times (in cycles and fraction of the last cycle). The Doppler observable is the average change in phase over the count or sample time (the phase difference divided by the count time), and is thus a differenced range measurement and not an instantaneous line-of-sight velocity (see Moyer, 1971).

The transmitting frequency can either be constant or ramped (linear with time). The majority of the PVO data have constant transmitting frequencies and the Magellan data were ramped until November 19, 1993 and mostly constant thereafter. From August 1993 to November 1993 for Magellan, there were some instances of incorrect reporting of the ramp rates in the last significant digit. There is no listing of these ramp errors but the error can be noticed in the residuals because of the discontinuity it causes in the observable on the order of 1 mm/s. If this discontinuity does not match with the momentum wheel desaturations, then it is probably a ramp error and it can be removed by increasing or decreasing the ramp rate by 0.000005 Hz/sec. In addition for Magellan, there are several occurrences in cycle 5 (mostly December 1993 and January 1994) where the incorrect reference frequency is reported, and this required the estimation of a Doppler bias on the order of 1000 mm/s. The reference frequency was not chosen as an integral number and thus was truncated to fit within the file format. Again for Magellan, there are also instances where one-way Doppler data were reported as two-way Doppler data, but these are easily identified as blunder points. The Doppler data file formats (ODF, Orbit Data File, and ATDF, Archival Tracking Data File) are available from the Geosciences Node, Planetary Data System (PDS), at Washington University in St. Louis, Missouri or from parts of a JPL DSN document that were contributed by Goltz (1988a and 1988b).

The major contribution to the observable is the relative velocity of Venus with respect to the Earth which varies between ±13 km/s. Since the noise of the Magellan X-band observable is less than 0.1 mm/s, this is a measure of the Venus-relative-to-Earth ephemeris in the tenth significant digit. The next major contributor to the observable is the orbit velocity of the spacecraft about Venus which varies between 1 and 9 km/s. The last major contributor to the observable is the motion of the Earth station with a velocity less than 0.5 km/s.

Table 1. Tracking Station Cylindrical Coordinates.

DSN Station	Longitude (deg)	Z height (km)	Spin radius (km)
11	243.150581357	3673.7640164	5206.3398806
12	243.194514844	3665.6309210	5212.0544322
13	243.205115543	3660.9568700	5215.4841386
14	243.110465567	3677.0522364	5203.9968496
15	243.112808584	3676.6699703	5204.2342885
16	243.126353832	3669.3861410	5209.3695231
42	148.981263719	-3674.5822320	5205.3523453
43	148.981263716	-3674.7487034	5205.2514376
44	148.977789576	-3691.3475374	5193.9817946
45	148.977682009	-3674.3815553	5205.4946063
46	148.983078061	-3674.9756700	5205.0754067
61-34m	355.750974037	4114.8843050	4862.6104361
61-26m	355.750974037	4114.8823280	4862.6081161
62	355.632163870	4116.9054796	4860.8179889
63	355.751987690	4115.1089216	4862.4509999
65	355.748578096	4114.7486263	4862.7173018
66	355.748529707	4114.9997980	4862.5302573

Table 2. DSN Plate Motion Velocities in cm/year.

Complex	East	North	Vertical
Goldstone (10)	-1.98	-0.57	-0.01
Canberra (40)	1.97	5.06	0.01
Madrid (60)	2.11	2.55	0.11

3b. Geometric Models

The planetary ephemeris is given by the state of the art JPL model DE403 as described by Standish et al (1995), and is a significant improvement over JPL model DE200 (Standish, 1990). The accuracy of DE403 is almost an order of magnitude better then DE200 for the Venus line-of-sight velocity with respect to the Earth. DE403 is oriented with respect to the International Earth Rotation Service (IERS) coordinate frame and is consistent with the IERS station coordinates that are used in this gravity solution. The initial state of the Earth and Venus are also estimated using the Set III variables of Brouwer and Clemence (1961).

The station locations are given by JPL VLBI solution "SSC(JPL) 91 R 01" which was submitted to the 1990 IERS Annual Report (Steppe et al, 1991). The station positions are listed in Table 1. They are in the IERS frame with respect to a 1988.0 epoch and include vertical corrections when used for Doppler measurements instead of VLBI measurements (7 cm for the 70m antennas and 1.5 cm for the 34m HEF X-band stations, Folkner, 1992b). The coordinates are for the geocentric metric and are scaled to the barycentric metric by the Orbit Determination Program (ODP, Moyer, 1990); this scaling has a 0.01 mm/s signature in the Doppler. The relative position uncertainty between stations is about 2-3 cm per component with a geocentric uncertainty of about 10cm

(Folkner, 1992a). The plate motion model is given by ITRF93 of IERS (Boucher et al, 1994) and is listed in Table 2. The combined uncertainties in the station positions and plate motion model result in errors in the Doppler observable of 0.01 mm/s or less for both the PVO and Magellan Doppler data. The PVO spacecraft was tracked by DSN stations 11, 12, 14, 42, 43, 44, 61, 62, and 63, and Magellan by stations 12, 14, 15, 42, 43, 45, 61, 63, and 65. The positions of stations 11, 44, and 62 are given by Moyer (1989) with respect to the 70m stations (14,43,63) from intercomplex survey data (to an accuracy of about 10cm). However, all the tracking stations for Magellan are given by Steppe et al (1991). Station 61 was upgraded from a 26-meter antenna to a 34-meter antenna during August 9, 1979 to March 31, 1980 (Moyer, 1983). The station platform was raised exactly 10 feet and this is reflected in the station coordinates given in Table 1. (Station 12 was also upgraded and raised to a 34m antenna from June 1, 1978 to December 1, 1978, but this is prior to the orbit insertion for PVO). The two-way X-band data are transmitted and received by only the 34m HEF stations 15, 45, and 65. The station coordinates are corrected by the ODP for solid earth tides (0.015 mm/s amplitude in Doppler) and pole tide (<0.001 mm/s).

The Earth orientation parameters (UT1-TAI, TAI-UTC, and polar motion) are given by the University of Texas, Center for Space Research solution "EOP(CSR) 95 L 01" submitted to IERS (1994 IERS Annual Report) for Magellan data and JPL solution "EOP(JPL) 91 C 01" submitted to IERS (Gross, 1992, also called Space91) for PVO data. For Magellan, the IERS solutions for UT1 and polar motion are better than 0.01 millisec and 0.1 milliarcsec, and the solution uncertainties for the PVO time frame are at least an order of magnitude greater than these values (1994 IERS Annual Report). Figures 1, 2, and 3 show the differences between the UT1 and polar motion solutions of U. of Texas and Space91 for the PVO time frame. The Doppler signatures from these Earth orientation errors are about 0.02 mm/s for PVO and negligible for Magellan. A UT1 bias is estimated for each PVO arc with an a priori of 1 millisec, but the resulting estimate sigmas are not significantly improved. The precession and nutation models are given by the 1976 IAU precession (Lieske et al, 1977) and 1980 IAU nutation models (Seidelmann, 1982). Corrections to the IAU precession and nutation models have been applied using the terms from Folkner (1994a). The resulting error in the precession and nutation for the PVO and Magellan time frame (1979-1994) is less than 10 nrad (6 cm).

The DSN stations record the Doppler observation in Station Time (ST). The differences between ST and UTC at each station complex are available for the Magellan data but not the PVO data. The time differences for Magellan are less than one microsecond and contribute only a small signature to the Doppler residual (<0.01 mm/s). The conversion from UTC to TAI is then given by "EOP(CSR) 95 L 01" or "EOP(JPL) 91 C 01" and the ET-TAI calculation is outlined by Moyer (1981). The relativistic delay of the signal due to the gravitational mass of the Sun is given by Moyer (1977) as a function of the relativity parameter γ. This effect on the Doppler observable is on the order of 1 mm/s for the Sun and is negligible for the relativistic terms of the planets (< 0.002 mm/s).

A seasonal troposphere model for each DSN complex in the form of a Fourier series (see Estefan and Sovers, 1994) is applied to the Magellan and PVO observables. The errors in the seasonal model can be as large as 0.1 mm/s for the low elevation data. Future gravity solutions will include a daily tropospheric correction to the seasonal model for the Magellan Doppler data only (supplied by the JPL Tracking System Analytical Calibration or

Figure 1: Space91 and Texas UT1 Daily Differences

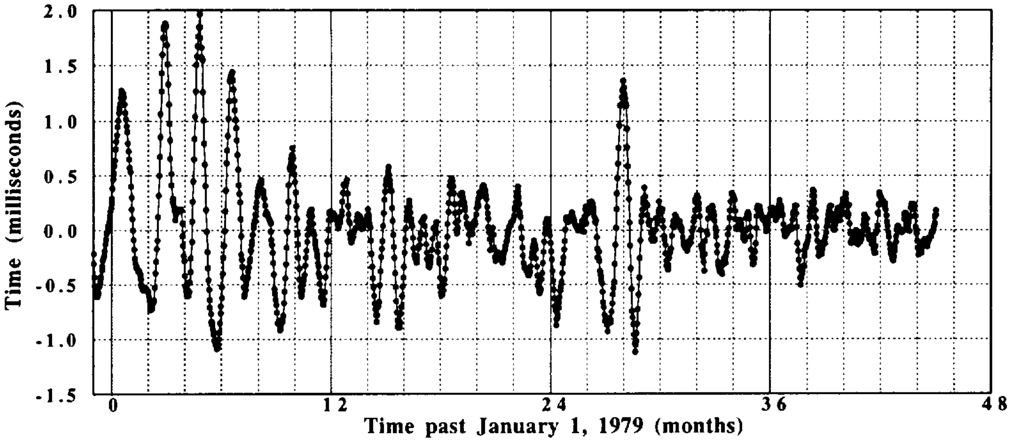


Figure 2: Space91 and Texas X-Pole Daily Differences

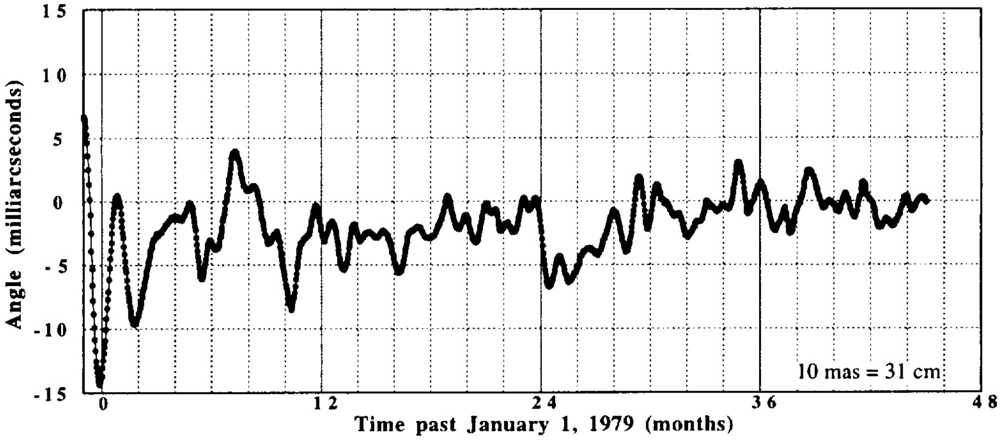


Figure 3: Space91 and Texas Y-Pole Daily Differences

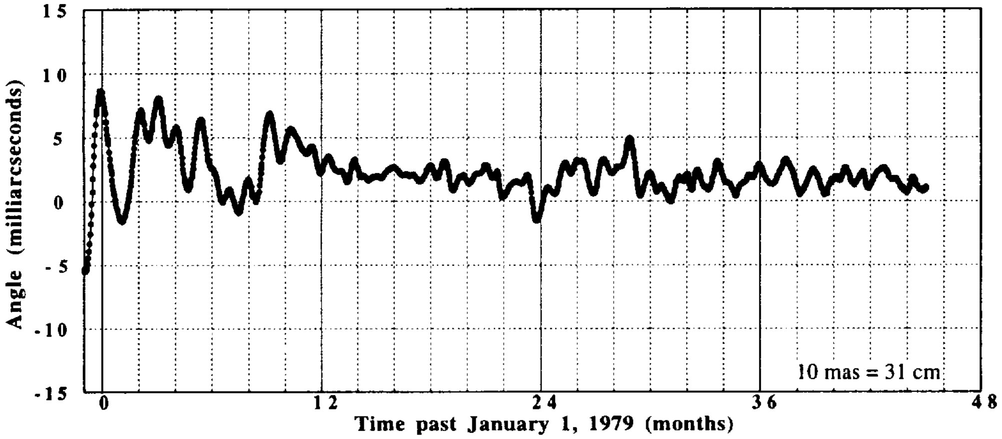
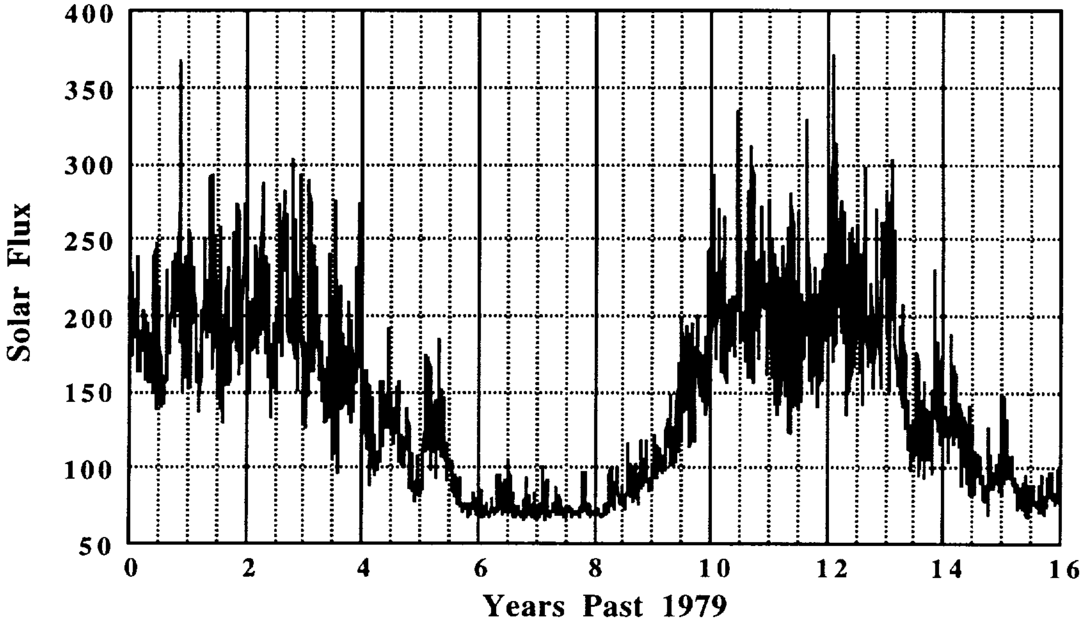


Figure 4: Daily Solar Flux for PVO and Magellan Time Frame



TSAC group and based upon weather data). At the present, any observations with an elevation below 10° are deleted.

The charged particle delay is a major effect for the Doppler S-band data (on the order of 1 mm/s) and is due to solar plasma and the Earth's ionosphere. Calibrations from the Earth's ionosphere were used for both PVO and Magellan (again provided by JPL TSAC) and are accurate to about 10% (Royden, private communication, JPL, 1995). However for the older PVO data, there are some time spans where Faraday rotation data could not be obtained. These times are the first three months of PVO data where no calibrations were used for Madrid and for March 1982 to June 1982 for Canberra which were filled in with an empirical seasonal (Bent et al, 1976) model prediction accurate to about 30%. The Magellan calibrations are based upon GPS data. The ionosphere delay is approximately proportional to the solar flux which is displayed in Figure 4, and all the PVO data are near maximum solar activity and the Magellan gravity data are near solar minimum. Some very limited PVO data exists with S-band and X-band downlink, and ionospheric delays for the downlink could be computed, but this has not been pursued. The charged particle delay uncertainty for the PVO data is the limit for much of the information that can be obtained from the data, such as the ephemeris of Venus.

3c. Dynamic Models

The dynamic models consist of all forces acting on the spacecraft. The gravitational attraction of the Sun and planets other than Venus are modeled as point masses with the positions given by the JPL DE403 ephemeris. The major contributor is the Sun with an acceleration of $1x10^{-9}$ km/s^2. The relativistic acceleration on the spacecraft (Moyer, 1971) is largest due to Venus and is about $1x10^{-9}$ km/s^2 at periapse with the Sun contribution four orders of magnitude smaller. The force is predominantly in the radial direction and inversely proportional to the distance squared (equivalent to a change in GM).

The gravitational potential of Venus is modeled by a spherical harmonic expansion with normalized coefficients ($\bar{C}_{nm}$, $\bar{S}_{nm}$) and is given by

$$U = \frac{GM}{r} + \frac{GM}{r} \sum_{n=2}^{\infty} \sum_{m=0}^{n} \left(\frac{a_e}{r}\right)^n \bar{P}_{nm}(\sin \phi) \left[\bar{C}_{nm} \cos m\lambda + \bar{S}_{nm} \sin m\lambda\right] \tag{1}$$

where n is the degree and m is the order, $\bar{P}_{nm}$ are the fully normalized associated Legendre polynomials, a_e is the reference radius of Venus (6051.0 km for our models), ϕ is the latitude, and λ is the longitude. The normalized coefficients are related to the unnormalized by (see Kaula, 1966)

$$(\bar{C}_{nm} \ ; \ \bar{S}_{nm}) = \left[\frac{(n+m)!}{(2-\delta_{0m})(2n+1)(n-m)!}\right]^{1/2} (C_{nm} \ ; \ S_{nm}) \tag{2}$$

where δ_{0m} is the Kronecker delta function and $\bar{C}_{n0} = -\bar{J}_n$. The harmonic coefficients of degree one are fixed to zero since the origin of the coordinate system is chosen to be the center of mass of the body. The body-fixed coordinate system is nominally given by the 1991 IAU values (Davies et al, 1992a, 1992b) for Venus pole position and rotation rate. The pole and rate are fixed to the 1991 IAU values for the final gravity solution delivered to the scientific community. However, we also present below our solutions for the pole and rate.

The normalized gravity coefficients are estimated complete to degree and order 90 (8277 coefficients). However, the gravity analysis for Venus is not complete with a 90th degree and order solution. The Magellan Doppler tracking data contain information about the Venus gravity field to about harmonic 120 for much of the planetary surface with the equatorial band resolution perhaps to degree 180 (Kaula, 1995). Determination of a higher degree and order gravity field for Venus will be a part of future work. A 120th degree and order field (15,000 parameters) is easily within reach on the JPL Cray T3D Supercomputer. The nominal gravity field for this 90th degree solution (MGNP90LSAAP) is the previous 90th degree solution (or iteration, MGNP90KSAAP).

Also modeled and estimated is the tidal effect on Venus due to the Sun. This force causes a time varying component of the second degree harmonics as a function of the body-fixed position of the Sun. The relationships for corrections to the normalized coefficients are (see McCarthy et al, 1989)

$$\Delta\bar{C}_{20} = \frac{1}{\sqrt{5}} k_2 \frac{GM_s R^3}{GM_v r_s^3} \left[\frac{3}{2} \sin^2\phi_s - \frac{1}{2}\right]$$

$$\Delta\bar{C}_{21} = \sqrt{\frac{3}{5}} k_2 \frac{GM_s R^3}{GM_v r_s^3} \sin \phi_s \cos \phi_s \cos \lambda_s$$

$$\Delta\bar{S}_{21} = \sqrt{\frac{3}{5}}\, k_2 \,\frac{GM_sR^3}{GM_v r_s^3} \sin\phi_s \cos\phi_s \sin\lambda_s$$

$$\Delta\bar{C}_{22} = \sqrt{\frac{3}{20}}\, k_2 \,\frac{GM_sR^3}{GM_v r_s^3} \cos^2\phi_s \cos 2\lambda_s \qquad (3)$$

$$\Delta\bar{S}_{22} = \sqrt{\frac{3}{20}}\, k_2 \,\frac{GM_sR^3}{GM_v r_s^3} \cos^2\phi_s \sin 2\lambda_s$$

where ϕ_s is the latitude of the Sun, λ_s is the longitude of the Sun, and M_v is the mass of Venus. The Love number k_2 is estimated. Since the latitude of the Sun is only a few degrees, the only significant time varying term occurs for the $\bar{C}_{22}$ and $\bar{S}_{22}$ coefficients. The expected amplitude for the normalized coefficients for a Love number of 0.25 is 7.1×10^{-9}; the other periodic terms have amplitudes two orders of magnitude smaller. If the Doppler tracking data determine the $\bar{C}_{22}$ and $\bar{S}_{22}$ coefficients to this level over various solar longitudes then the tidal effect of Venus can be determined. The solution for $\bar{J}_2$ given in this report has the permanent (or constant) part of the tide removed from it. To get the total $\bar{J}_2$, one must add 4.1×10^{-9}.

A major dynamic effect on the spacecraft is atmospheric drag with alongtrack accelerations for PVO reaching 1×10^{-6} km/s^2 for the daytime atmosphere at 150 km altitude. The density profile for the Venus atmosphere is given by the Venus International Reference Atmosphere (VIRA) model. It is a multilayered exponential model with density values at 5-km intervals in altitude and profiles given at different local solar times (Keating et al, 1985). The local solar time (LST) is defined by the direction of Venus rotation which is retrograde (the morning terminator=6am), and is the angle between the longitude of periapse and the longitude of the Sun. The 23 total atmospheric layers extend from 140 km to 250 km altitude and the VIRA model is symmetric about noon and midnight LST. The atmospheric drag on the orbit is estimated for every periapse passage for both Magellan and PVO. The exponential scale-height values for each layer are held fixed and the density at the lowest layer of 140 km is estimated (thus changing the density at each layer). For periapse altitudes above 250 km (including the 1000-km altitude PVO data), a single-layered atmosphere is used with scale-height values remaining a function of LST. Table 3 gives the scale height for each layer of the VIRA model and the base density at 140 km. For a given spacecraft LST at periapse, the atmospheric densities are determined by linearly interpolating the corresponding densities from Table 3.

For the PVO low-altitude data, a lift to drag coefficient is estimated for every data arc. The PVO spacecraft is basically a cylinder (with the antenna being a smaller component) and with the axis of symmetry pointed to the north ecliptic. The cylinder has a radius of 50 inches and a height of 48 inches. Since PVO approaches periapse from the northern latitudes, the angle of attack (the angle between the symmetry axis and the velocity vector) is about 22° and so the flat plate at the base of the cylinder is the major contributor to the lift force. For free molecular flow, the coefficient of lift to drag, $C_{l/d}$, should be in the direction away from Venus (this is a negative $C_{l/d}$ as given by the ODP software).

Table 3. VIRA Atmosphere Model.

Altitude (km)	Midnight	Local Solar Time 5	6	7	8	10	Noon
			Base Density, 10^-12 (gm/cm^3)				
140	0.31	0.48	1.15	2.52	3.58	3.09	6.13
			Scale Heights (km)				
140	4.1	4.4	4.4	4.8	5.0	6.6	5.3
145	5.1	5.4	5.2	5.5	5.7	6.6	5.8
150	6.1	6.5	6.1	6.3	6.5	6.6	6.3
155	6.9	7.7	7.3	7.2	7.4	7.5	7.1
160	7.4	8.7	8.6	8.3	8.4	8.4	8.0
165	7.7	9.7	9.8	9.5	9.5	9.5	8.9
170	8.1	10.4	11.0	10.7	10.6	10.7	10.0
175	8.5	11.0	11.9	11.8	11.8	11.8	11.1
180	9.0	11.9	12.7	13.0	13.1	12.8	12.2
185	9.7	12.2	13.2	13.9	13.8	13.8	13.4
190	10.9	13.1	13.9	14.6	14.8	14.9	13.9
195	12.7	14.2	14.1	15.2	15.6	15.4	14.9
200	15.4	15.5	14.5	15.7	16.2	16.0	15.5
205	19.3	17.0	14.9	16.1	16.7	16.6	15.9
210	24.3	19.1	15.4	16.4	17.0	16.8	16.5
215	30.7	21.3	15.6	16.7	17.5	17.2	16.7
220	36.5	24.9	16.4	17.0	17.6	17.4	16.9
225	43.6	27.3	16.7	17.2	17.9	17.7	17.4
230	50.6	31.0	17.8	17.2	18.1	17.9	17.5
235	55.2	34.9	18.6	17.6	18.3	18.1	17.7
240	59.5	38.4	19.7	17.6	18.3	18.1	17.8
245	62.1	41.5	21.1	18.5	18.8	18.3	18.1
250	62.1	41.5	21.1	18.5	18.8	18.3	18.1

The solar radiation pressure force for both PVO ($1.3\text{x}10^{-10}$ km/s^2) and Magellan ($2.7\text{x}10^{-10}$ km/s^2) is accounted for in each arc by estimating one coefficient in each of three orthogonal directions (Sun-spacecraft line, ecliptic north direction, and in the ecliptic normal to the Sun-spacecraft direction). The PVO spacecraft is a simple spinning cylinder with a smaller antenna continuously pointed to Earth. The coefficients will change with time due to the change in antenna position. This is noticeable in the high-altitude PVO data. The Magellan spacecraft, however, goes through many orientation changes to either heat up or cool down ("hide") the spacecraft. These changes are modeled by estimating an acceleration vector for each hide, and may be as short as 10 minutes or as long as two hours. The spacecraft orientation is changed with the momentum wheels and there is no thrusting. The acceleration thus absorbs the change in the solar pressure force on the spacecraft due to the new orientation. Also, the Magellan spacecraft goes through an orientation change near apoapse for star calibration. In that case, the solar pressure force change is modeled with a small (a priori of 0.3 mm/s) delta velocity estimation. With the current arc lengths of one day for Magellan, these small solar pressure effects (hides, star calibrations) are small and have negligible effects on the gravity estimation. However, with longer data arcs, these effects may become important. The hide history for Magellan is listed in Appendix F.

The radiation force from Venus albedo is a ring model (Knocke and Ries, 1987) where a simple bus model is used for Magellan and a cylindrical model is used for PVO. The albedo force is basically undetermined for Magellan and the low-altitude PVO data due to the atmospheric drag. For the high-altitude PVO, the albedo force is significant. The mean albedo value is 0.76 (Taylor et al, 1983) and variations in albedo are allowed for by estimating a scale factor for the albedo for each data arc. The albedo force is approximately 1×10^{-10} km/s^2, and is about four times smaller than the tidal force (k_2). The radial components of the tide, albedo, and drag forces for PVO and Magellan are displayed in Figures 5, 6, 7, and 8. The examples are for orbits with a local solar time near noon. The drag force for the high-altitude PVO orbits is several orders of magnitude smaller than the albedo and tidal forces, but reaches 1×10^{-8} km/s^2 in the radial direction for the low-altitude PVO orbits. In solutions for these forces, the tide generally correlates with the initial spacecraft state and solar pressure and albedo with the drag due to a nonconservative part of the force (the albedo force has a mean acceleration in the velocity direction). The variational equation for the semi-major axis (a) is (Battin, 1987)

$$\frac{da}{dt} = \frac{2va^2}{GM_v} a_{dt} \qquad (4)$$

where v is the spacecraft velocity, a_{dt} is the acceleration along the velocity direction. Even though the tide force is also larger than albedo in the along-track direction, the average rate of change of the semi-major axis (the integral over one orbit in equation (4)) for the albedo force is an order of magnitude greater (1 m/day vs 0.1 m/day) than the tide or drag. The formal uncertainty in the semi-major axis for the high-altitude 3-day PVO arcs is about 2 meters. Hence, the albedo is fairly well determined for the PVO high-altitude orbits but the tidal effect is better determined for the low-altitude orbits. The drag force is substantially lower for Magellan than PVO due to higher altitudes and lower spacecraft velocity through the atmosphere. The drag force for the near circular orbit is even lower still for the same reasons. The tidal force can, in part, be better separated from the other forces because on the nightside of Venus the tidal force remains the same, the albedo force vanishes, and the drag force diminishes by an order of magnitude.

The Magellan spacecraft attitude was maintained with the use of momentum wheels, and they were also used to change the orientation of the spacecraft. These changes did not impart any force on the spacecraft. However, due to atmospheric drag torques on the spacecraft, the momentum wheels had to be despun or desaturated every orbit or about 8 times per day for cycle four and 15 times per day for cycles five and six. Prior to the gravity cycles, the desaturations occurred about three times per day. The desaturations imparted an incremental velocity to the spacecraft of about 1 mm/s and required estimation of the three components of the velocity vector. These desaturations greatly reduced the long term gravity information in the Magellan data.

All the above forces on the spacecraft are included in the numerical integration of the spacecraft state ($d^2\mathbf{r}/dt^2$ = forces) in rectangular coordinates of the Earth mean equator of J2000 coordinate system. The integrator is a multistep Adams type predictor-corrector that varies the order to obtain the largest possible step size. We use an absolute integration

Figure 5: Radial Acceleration Profile for High-Altitude PVO

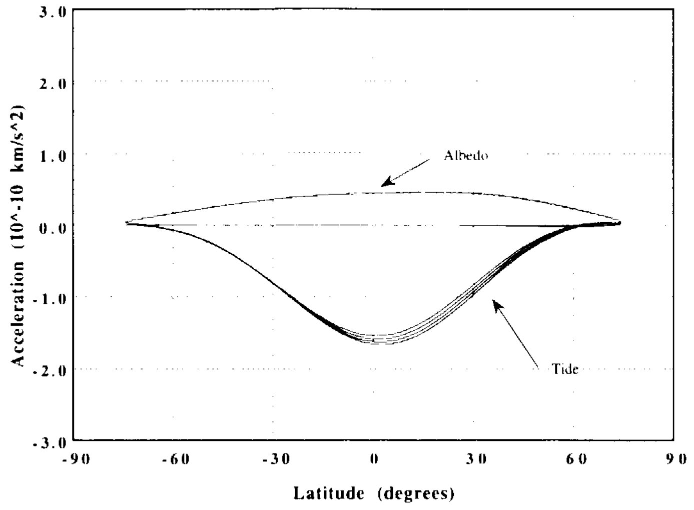


Figure 6: Radial Acceleration Profile for Low-Altitude PVO

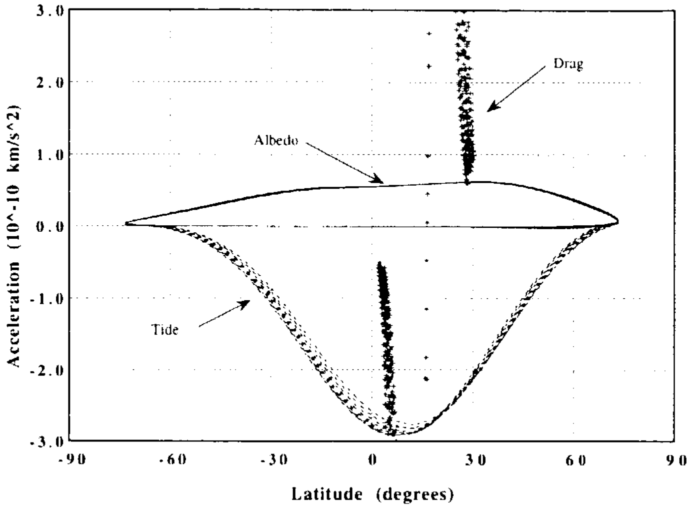


Figure 7: Radial Acceleration Profile for Magellan Cycle 4

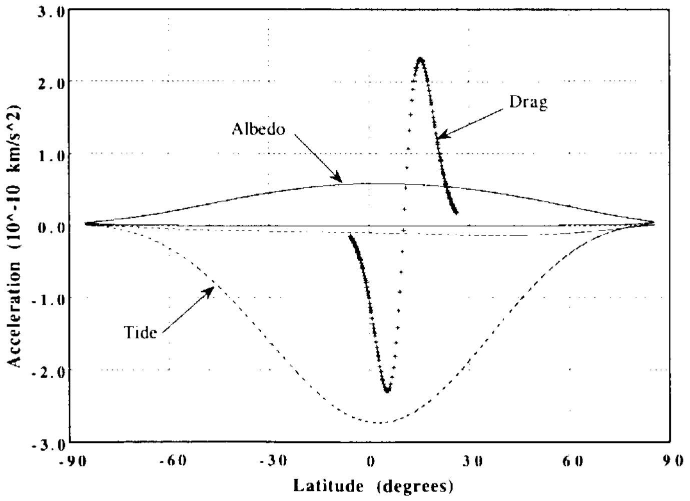
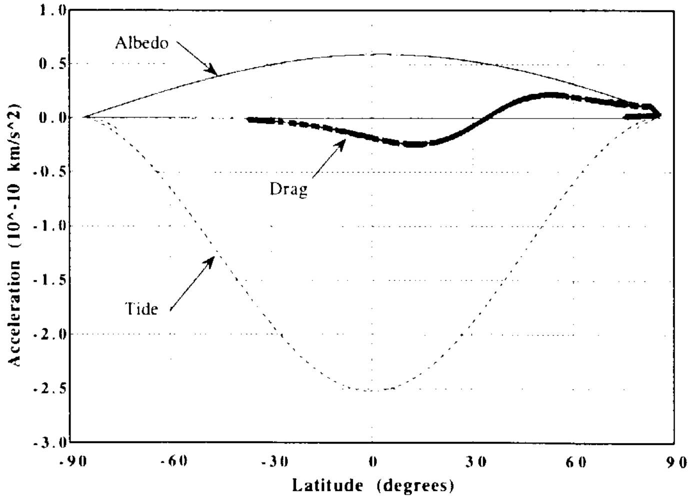


Figure 8: Radial Acceleration Profile for Magellan Cycle 5&6



tolerance of 2×10^{-11}, and this results in numerical noise for the Doppler observable of less than 0.01 mm/s.

4. Estimation Procedure

4a. Determination of Unconstrained Gravity Field

The JPL gravity estimation software is based upon the Orbit Determination Program or ODP (see Moyer, 1971); the software set used at JPL for navigation of all planetary spacecraft. This FORTRAN code was used for the numerical integration and processing of the Doppler observable to produce an observation equation (using all the geometric and dynamic models discussed above). The ODP was modified by the authors for use on the JPL Cray T3D supercomputer, a parallel computer with 256 DEC alpha processors. The filter which then processes the observation equations, however, was written specifically for the Cray T3D (by C.L. Lawson at JPL, for more specific details of the T3D software see Konopliv, 1995b). The use of the Cray has dramatically reduced the amount of computer time from years to days to generate the gravity solution. The spacecraft state and other parameters are estimated using a weighted least-squares filter based upon the square root of the information matrix (see Lawson and Hanson, 1995; Bierman, 1977). The parameters that are estimated consist of arc-dependent or local variables (spacecraft state, atmospheric densities, etc.) that are determined separately for each data arc (i.e., the arcs listed in Appendix F) and global variables (harmonic coefficients, etc.) that are common to all the data arcs.

Initially, we converge the data arcs by estimating only the local variables using the nominal values for the global variables. The observations of each arc are weighted according to data root mean square (rms) of that arc with a separate rms for each tracking station pass and with the rms including corrections for the count times of the observations. The actual data weight used is the rms multiplied by a factor of two with an additional correction factor for the observation elevation. Since the PVO and Magellan orbits are nearly polar, the groundtracks converge near the pole and the observations become more dense. For this reason, the observation sigma is adjusted for latitude ϕ ($\sigma_{new} = \sigma_{old}*\cos^{-1/2}\phi$).

The Doppler data (i.e. in the frequency domain, f) are treated as white noise, and theoretically, the rms of the data is inversely proportional to the square root of the sample time. However, due to the charged particle effects of the solar plasma, the noise follows a $f^{-8/3}$ power spectrum instead of the white f^{-2} spectrum (Folkner, 1994b). This is true for count times greater than about one minute; for count times shorter than one minute, the noise is white. This implies that there is more noise in the data for the longer count times than what is modeled. As a result, the uncertainties from the estimation process are too small (or optimistic) for the shorter wavelengths of the gravity field and too large (or pessimistic) for the longer wavelengths. At this time we have not devised a method to account for this noise spectrum. For the $f^{-8/3}$ spectrum, the rms is inversely proportional to the sixth root of the sample time.

Once the local variables are converged, the global parameters are determined with a technique described by Ellis (1980) that merges only the global parameter portion of the square root information (or SRIF) arrays from all the arcs, but is equivalent to solving for the global parameters plus local parameters of all arcs. For each data arc, the local variables estimated are the spacecraft state, three solar pressure coefficients, a factor for the Venus albedo, the base density for each periapse passage through the atmosphere, the lift-to-drag coefficient for the low-altitude PVO orbits, velocity vector increments for the momentum wheel desaturations and star calibrations of Magellan, acceleration vectors for the hides of Magellan, and a UT1 bias for the PVO arcs. The a priori uncertainties for the spacecraft state are large (20 km). The a priori base density uncertainties for the PVO orbits are large but are more tightly constrained for Magellan ($1 \times 10^{-12} \pm 1 \times 10^{-12}$ gm/cm^3). Future work will constrain the Magellan base densities more closely to the VIRA model. The a priori on the Magellan desaturations are 5×10^{-6} km/s and for the star calibrations are 3×10^{-7} km/s. The hides are constrained to 10^{-10} km/s^2.

The following global parameters are estimated: the normalized spherical harmonic coefficients ($\bar{C}_{nm}$, $\bar{S}_{nm}$) of the gravity field complete to degree and order 90, the gravitational constant times the mass of Venus (GM), the ephemerides of Earth and Venus (12 parameters), the Love number for Venus, the right ascension and declination of the Venus spin axis or pole, and the rotation rate for Venus. An SRIF array for the global parameters is obtained for three data sets (PVO, Magellan cycle four, and Magellan cycles five and six) where there is no constraint on the global variables. Combinations of these SRIF arrays together with a priori constraints on the global parameters are used to find solutions for the global variables. The a priori constraint on the gravity field is discussed in the next section.

4b. Gravity A Priori

Once all the global information is packed from all the data arcs, the gravity field is constrained with an a priori. The common method is to constrain each harmonic coefficient toward zero with an uncertainty given by the Kaula rule (Kaula, 1966) for that particular planet (used, for example, in Konopliv et al. 1993a, Konopliv et al. 1993b, Nerem et al. 1993, McNamee et al. 1993, Smith et al., 1993, Lemoine, 1992, Lemoine et al 1995). The Kaula rule used for Venus is $1.2 \times 10^{-5} / n^2$ where n is the degree of the coefficient. The second a priori constraint method is a spatial constraint and is also outlined for Mars in Konopliv and Sjogren (1995a).

The a priori constraint applied for this gravity field evaluates the radial acceleration and its uncertainty on the reference sphere (i.e., $r = a_e$). At that surface, the radial acceleration (a_n) from all coefficients of degree n is given by

$$a_n = \frac{GM}{a_e^2}(n+1)\sum_{m=0}^{n} \bar{P}_{nm}(\sin\phi)\,(\bar{C}_{nm}\cos m\lambda + \bar{S}_{nm}\sin m\lambda) \tag{5}$$

To create a profile of acceleration contributions versus degree, the rms of the acceleration a_n is obtained over the sphere. The mean of the square of the acceleration $(a_n)_{ms}$ of equation (5) is given by

$$(a_n)_{ms} = \left[\frac{GM}{a_e^2}(n+1)\right]^2 \frac{1}{4\pi} \times$$
$$\int_0^{2\pi}\int_{-\pi/2}^{\pi/2} \left[\sum_{m=0}^{n} \bar{P}_{nm}(\sin\phi)(\bar{C}_{nm}\cos m\lambda + \bar{S}_{nm}\sin m\lambda)\right]^2 \cos\phi \, d\phi \, d\lambda$$

Since the spherical harmonics are orthogonal, we obtain

$$(a_n)_{ms} = [\frac{GM}{a_e^2}(n+1)]^2 \sum_{m=0}^{n} (\overline{C}_{nm}^2 + \overline{S}_{nm}^2)$$

As a good approximation, the rms magnitude spectrum of the gravity coefficients follows the Kaula rule and is given by

$$\left[\frac{\sum_{m=0}^{n} (\overline{C}_{nm}^2 + \overline{S}_{nm}^2)}{2n+1} \right]^{1/2} = K/n^2$$

where K is the constant for the particular planet (1.2×10^{-5} for Venus). The expected acceleration profile is then given by (for n >> 1)

$$(a_n)_{rms} = \frac{GM}{a_e^2} K\sqrt{2/n} \tag{6}$$

which for Venus is

$$(a_n)_{rms} = 15 / \sqrt{n} \text{ milligals} \tag{7}$$

This is the expected "signal" for the acceleration at each point on the surface of the reference sphere. The signal could also be determined empirically by taking the rms of a given gravity field over different regions. However, for this work, only one signal profile is used for all latitudes and longitudes.

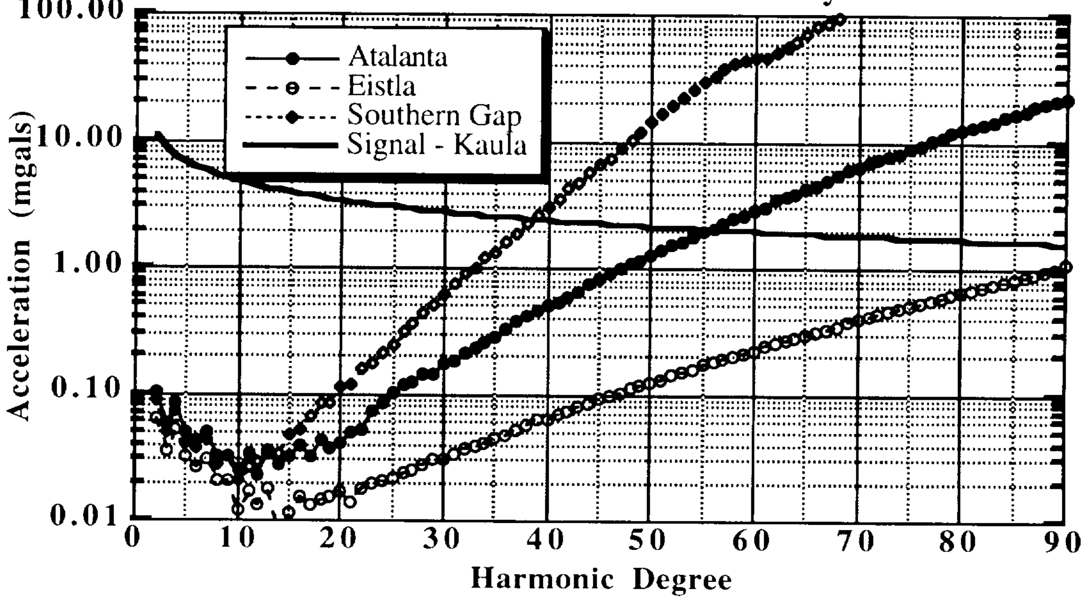
The next task is to map the acceleration uncertainty at the surface into an uncertainty or "noise" profile showing the error in acceleration versus harmonic degree. The acceleration uncertainty from the summed contributions of all coefficients from degree 2 to n, $\sigma(a_{2,n})$, is given by

$$\sigma(a_{2,n}) = \frac{\partial a_{2,n}^T}{\partial \mathbf{G}_{2,n}} \mathbf{P}_{noap(2,n)} \frac{\partial a_{2,n}}{\partial \mathbf{G}_{2,n}}$$

where $\mathbf{G}_{2,n}$ is the vector of all normalized gravity coefficients from degree 2 to n and $\mathbf{P}_{noap(2,n)}$ is the corresponding covariance. The covariance of the coefficients from degree 2 to n is the covariance as if the higher degree coefficients (>n) are not estimated. Hence, it is a truncation, or submatrix, of the full 90th degree and order covariance without any constraint applied to the gravity field. The partial of the acceleration with respect to the coefficients of degree n and order m are functions of latitude and longitude and are given by

$$\frac{\partial a_{2,n}}{\partial \overline{C}_{nm}} = \frac{GM}{a_e^2}(n+1)\overline{P}_{nm}(\sin\phi)\cos m\lambda \tag{8}$$

Figure 9: Acceleration Profiles for Venus Unconstrained Surface Gravity



$$\frac{\partial a_{2,n}}{\partial \bar{S}_{nm}} = \frac{GM}{a_c^2} (n + 1) \bar{P}_{nm}(\sin \phi) \sin m\lambda$$

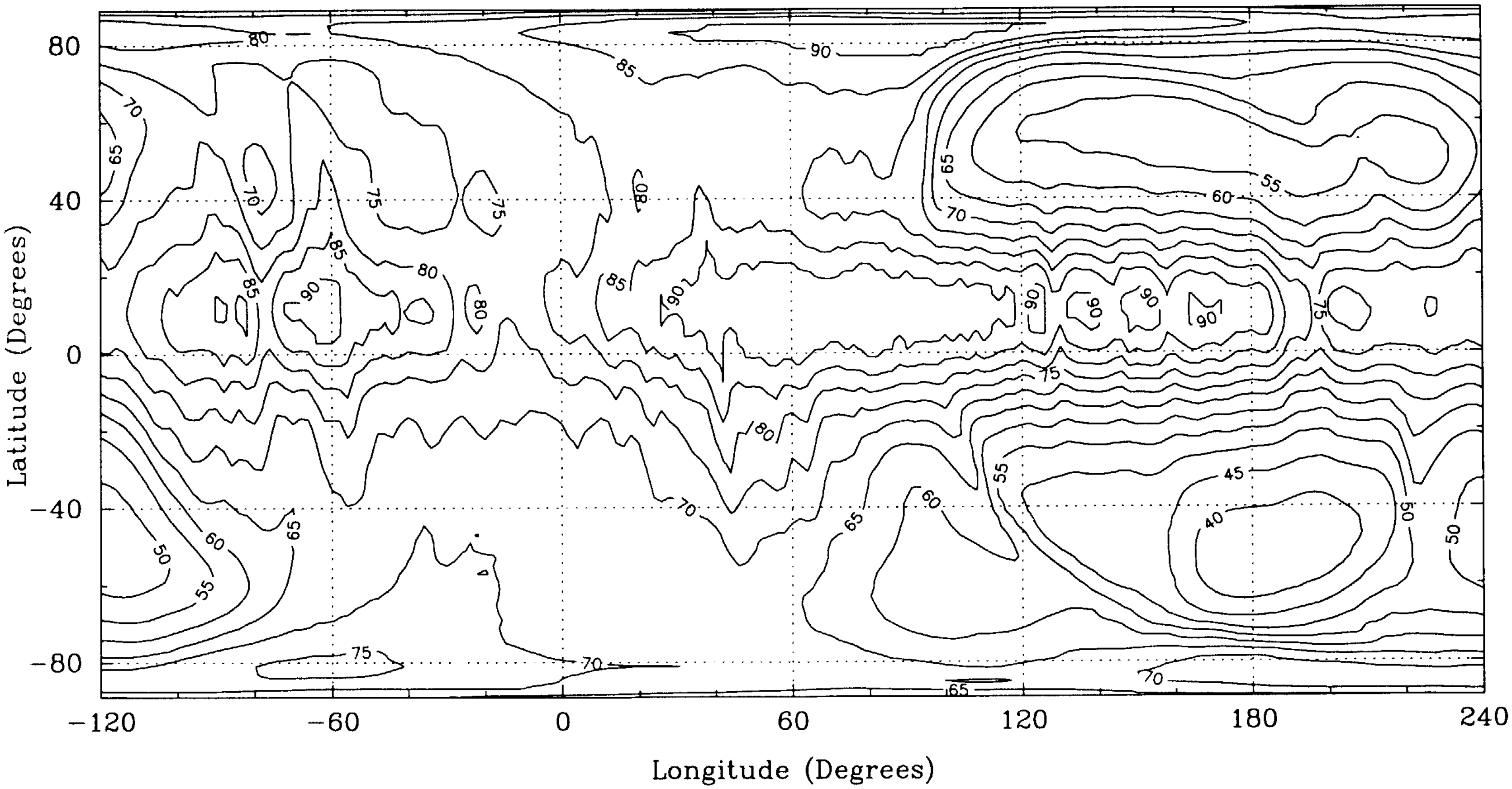
The uncertainty for the coefficients of degree n, $\sigma(a_n)$ is then given by the difference of the sum total error to degree n and the sum total error to degree n-1 as

$$\sigma(a_n) = \sigma(a_{2,n}) - \sigma(a_{2,n-1}) \tag{9}$$

Figure 9 shows the expected acceleration profile from the Kaula rule of equation (6) and the unconstrained acceleration uncertainty profile as given by equation (9) for Atalanta, the periapse region for Magellan cycle 4 (e.g. eastern Eistla Regio), and the gap in Magellan cycle 5 data in the southern hemisphere (160°E to 220°E, 30°S to 80°S). The crossing point of the Kaula signal with the acceleration uncertainty is called the degree strength of the gravity field for that particular latitude and longitude. For degrees greater than the degree strength, the "noise" in the data exceeds the "signal." Based upon the Kaula rule, the degree strengths for Atalanta, Eistla, and the southern gap are 55, 90, and 38, respectively. Figure 10 displays the degree strength on a global scale. The maximum degree strength is greater than harmonic degree 90 near the low-altitude periapse locations.

The basic idea of the gravity constraint method is to constrain the "noise" of the gravity field to zero with some uncertainty when the "noise" exceeds the "signal." The acceleration at the surface from all harmonic coefficients greater than or equal to the degree strength is constrained to zero with an uncertainty approximately equal to the expected signal at the degree strength. This amounts to generating observations over the entire

Figure 10: Degree Strength for MGNP90LSAAP



surface of the sphere based upon the degree strength at each latitude and longitude. An observation ($a_{D,90}$) for degree strength D is

$$a_{D,90} = \frac{GM}{a_e^2} \sum_{n=D}^{90} \sum_{m=0}^{n} (n + 1)\, \overline{P}_{nm}(\sin \phi)\, (\overline{C}_{nm}\cos m\lambda + \overline{S}_{nm}\sin m\lambda) \tag{10}$$

and the linearized observation equation is given by (Bierman, 1977)

$$z_i = \mathbf{A}_i\, \mathbf{x} + v_i$$

where z_i is the difference between the observed value (zero in this case) and the nominal value of the observation (the accumulated acceleration at the surface for degrees D to 90 from the a priori gravity model as given by equation (10)), $\mathbf{A}_i$ is the row vector of observation partials (the partial of the observation with respect to all the parameters being estimated), $\mathbf{x}$ is the vector of estimated parameters (differences in the gravity coefficients from the nominal gravity model), and v_i is the observation error. The partials $\mathbf{A}_i$ to construct the observation equation are

$$\mathbf{A}_i = \frac{\partial a_{D,90}}{\partial \mathbf{G}}$$

where $\mathbf{G}$ is the vector of all gravity coefficients. The elements of $\mathbf{A}_i$ for coefficients with degrees less than the degree strength D are zero and, otherwise, are again given by the partials of equation (8).

The observations are then merged with the unconstrained gravity SRIF array using Householder transformations. In normal form, the constrained gravity estimate $\mathbf{x}$ is written as

$$\mathbf{x} = \left[\mathbf{P}_{noap}^{-1} + \mathbf{A}^T\mathbf{W}\mathbf{A}\right]^{-1} \left[\mathbf{P}_{noap}^{-1}\mathbf{x}_{noap} + \mathbf{A}^T\mathbf{W}\mathbf{z}\right] \tag{11}$$

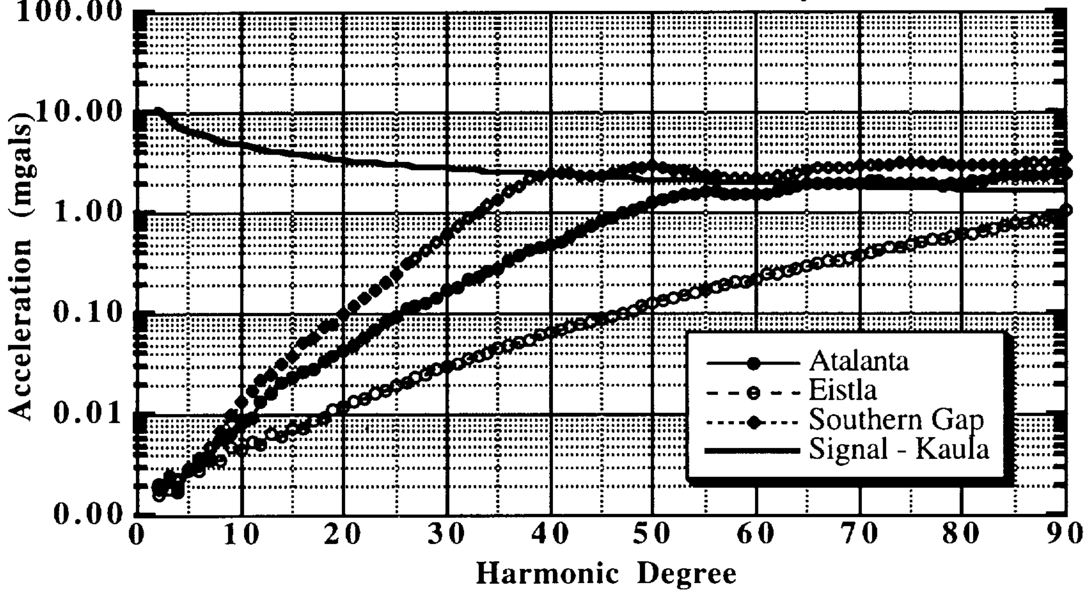
where $\mathbf{P}_{noap}$ is the unconstrained covariance of the gravity coefficients, $\mathbf{A}$ is the matrix of observation partials with each row an observation, $\mathbf{W}$ is the diagonal weight matrix, $\mathbf{x}_{noap}$ is the unconstrained gravity estimate, and $\mathbf{z}$ is the vector of linearized observations. The new constrained covariance $\mathbf{P}$ is then

$$\mathbf{P} = \left[\mathbf{P}_{noap}^{-1} + \mathbf{A}^T\mathbf{W}\mathbf{A}\right]^{-1} \tag{12}$$

The observations should be spaced such that at least three observations are generated over the shortest harmonic wavelength. The weight used for an observation is then proportional to the area between observations and is approximately equal to the signal at the degree strength (i.e., 10 to 20 milligals). The observations are globally spaced on a rectangular grid of latitude and longitude with a spacing of two degrees. To obtain truer peak values, there is no constraint around Maxwell Montes, Maat Mons, and Eistla and Beta Regio.

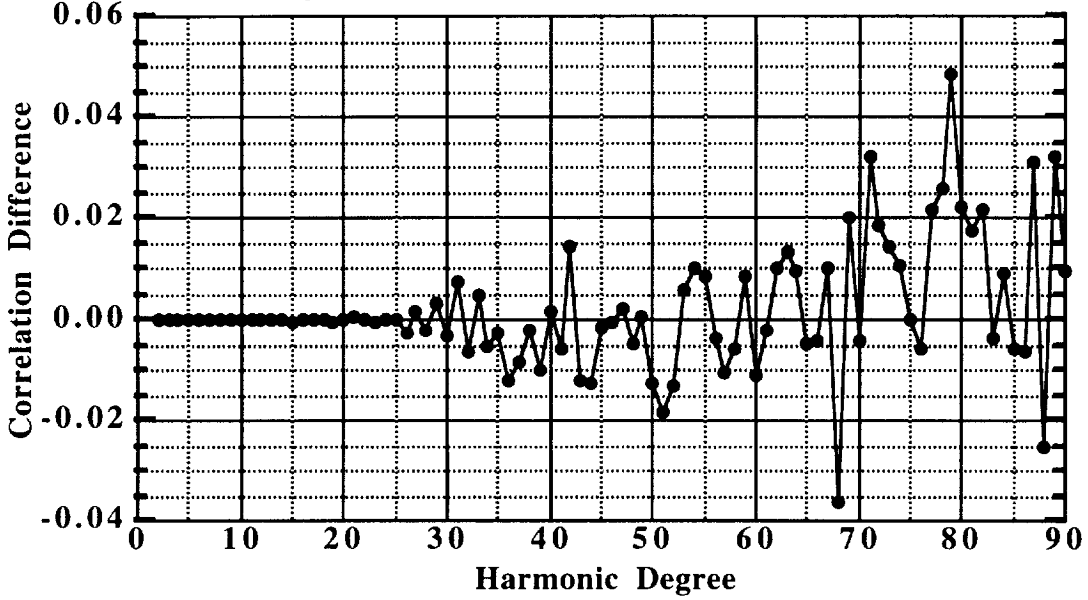
The result on the acceleration uncertainty profiles from applying the a priori observations on the gravity field is displayed in Figure 11 for the MGNP90LSAAP gravity

Figure 11: Acceleration Profiles for Venus Constrained Surface Gravity



field. The result for Atalanta and the Southern gap is an approximate Kaula constraint on the "noise" part of the spectrum. The uncertainties in the lower degree harmonics (up to degree 10) are one to two orders of magnitude greater for the unconstrained case (Figure 9)

Figure 12: Gravity Correlation with Topography of Surface Constraint Minus Kaula Constraint



versus the constrained (Figure 11). This is due to the lack of any constraint on the estimated parameters that are not gravity harmonics (Venus ephemeris, pole, and Love number) and is not due to the constraint on the higher degree coefficients.

The main advantage of using this spatial constraint instead of a straight Kaula rule on the spectrum appears to be better determination of peak amplitudes. Since the well determined degrees are not constrained directly (only somewhat through correlations), the amplitudes (and coefficients) for those degrees are not biased toward zero. It is also flexible in allowing relaxation of selected regions for any reason, such as incorrect data weighting or a region exhibiting greater signal than the power rule. The amplitudes are reduced by about 5 to 10% when a Kaula power law is applied versus the spatial constraint (e.g., 10 milligals for Maxwell Montes and Gula Mons, and 35 milligals for Maat Mons). The correlations with topography for the two different constraint methods are very similar. The correlations from the Kaula constraint are generally slightly higher for the medium wavelength harmonics and slightly lower for the higher frequencies (see Figure 12) with the sum of correlations over the degrees in favor of the surface constraint. In general, there are only slight differences between the methods since Venus does not have strong local deviations from Kaula power spectrum. For Mars, the differences are more pronounced for the Tharsis region (Konopliv and Sjogren, 1995a).

5. Gravity Results

5a. Global Gravity Model

The normalized coefficients of the nominal gravity solution (MGNP90LSAAP, SAAP = Surface Acceleration A Priori) are given in Appendix G up to degree and order 40. A file containing the complete field to degree and order 90 can be requested from the authors at ask@krait.jpl.nasa.gov or obtained from the Geoscience Node of the PDS at Washington University in St. Louis, Missouri (in the format specified by Simpson, 1993a). Also available from the Data Node are the covariance of the gravity harmonics (a 275 MB binary file, Simpson, 1993b), vertical surface gravity and error map (Simpson, 1995b), geoid and error map (Simpson, 1995b), and Bouguer map (Simpson, 1995b).

The GM solutions for Venus are given in Table 4 for different combinations of data. The 40th degree solutions are generated by fixing the coefficients from degree 41 to 90 at the values of the nominal gravity field (MGNP90KSAAP). The 40th degree solutions allow the Venus pole and rotation rate to move (i.e., they are estimated) and the 90th degree solutions hold the pole and rate to the nominal 1991 IAU values. The variations in the GM solution are generally one formal sigma with almost a two-sigma variation for the Magellan Cycle 4 data. The best GM solution with a realistic error is 324858.601±0.014 km^3/s^2 (2 x formal uncertainty). This solution agrees with our previous solutions within about two formal uncertainties. The ionosphere calibrations play a major role in the determination of the Venus GM from the PVO data, and their neglect may be a reason for unrealistically large values of previous solutions (our PVO solution without ionosphere calibrations jumps to about 324858.65).

Table 4. Gravitational Constant Times the Mass of Venus (GM in km^3/s^2).

Data Combination	Constraints	Solution	Formal Uncertainty
PVO	40, K, lp	324858.576	0.017
MGN Cycle 4	40, K, lp	324858.654	0.027
MGN Cycle 5	40, K, lp	324858.600	0.011
PVO+ MGN Cycle 4	40, K, lp	324858.589	0.011
ALL	40, K, lp	324858.600	0.007
PVO	90, K, lp	324858.581	0.018
MGN Cycle 4	90, K, lp	324858.649	0.028
MGN Cycle 5	90, K, lp	324858.605	0.011
PVO+ MGN Cycle 4	90, K, lp	324858.587	0.011
ALL	90, K, lp	324858.601	0.007
ALL (MGNP90LSAAP)	90, S, fp	324858.601	0.007

90, 40 = degree and order of solution, K = Kaula rule, S = Spatial (SAAP)
fp = fixed IAU pole, lp = loose pole (estimated pole and rotation rate for Venus)

Previous Solutions:		
Sjogren et al, 1990 (PVO Only)	324858.60	0.05
Nerem et al, 1993 (PVO Only)	324858.64	0.01
McNamee et al, 1993	324858.681	0.03
Konopliv et al 1994a, MGNP60FSAAP	324858.628	0.016
Konopliv et al, 1994b, MGNP75ISAAP	324858.589	0.006

The vertical (or radial) gravity at the reference surface (a sphere of 6051 km) is displayed in Figure 13 with contours every 20 milligals (10^{-8} km/s^2). The radial gravity is given by the partial of the potential, equation (1), in the radial direction without the central mass term but including J_2. A sphere is used as the reference surface for Venus since J_2 is small for Venus and comparable in size to the other spherical harmonics. The geoid or equipotential surface of equation (1) is given in Figure 14 with contours every 10 meters. The rotational contribution to the potential is neglected for Venus and the geoid is iterated to convergence. The difference between one and two iterations on the geoid or the error in Bruns' formula (Heiskanen and Moritz, 1967) is at most 3 cm in Atla and Beta Regio out of a 100+ meter geoid value.

The uncertainties in the vertical gravity and geoid are given in Figures 15 and 16. The uncertainties in the surface acceleration or potential are given by the errors up to the resolution or degree strength of the data plus the error for omission of terms beyond the resolution. From Figure 11, the uncertainties from the higher order terms (> degree strength) generally follow the Kaula power rule. So Figures 15 and 16 provide realistic errors for terms up to degree and order 90. Figure 17 shows the error in the vertical gravity up to the degree strength (i.e., the unconstrained covariance $\mathbf{P}_{noap}$ is truncated at the degree strength for that given latitude and longitude). The error in the gravity field that the data can

Figure 13: Vertical Gravity of Venus at the Surface (mgals)

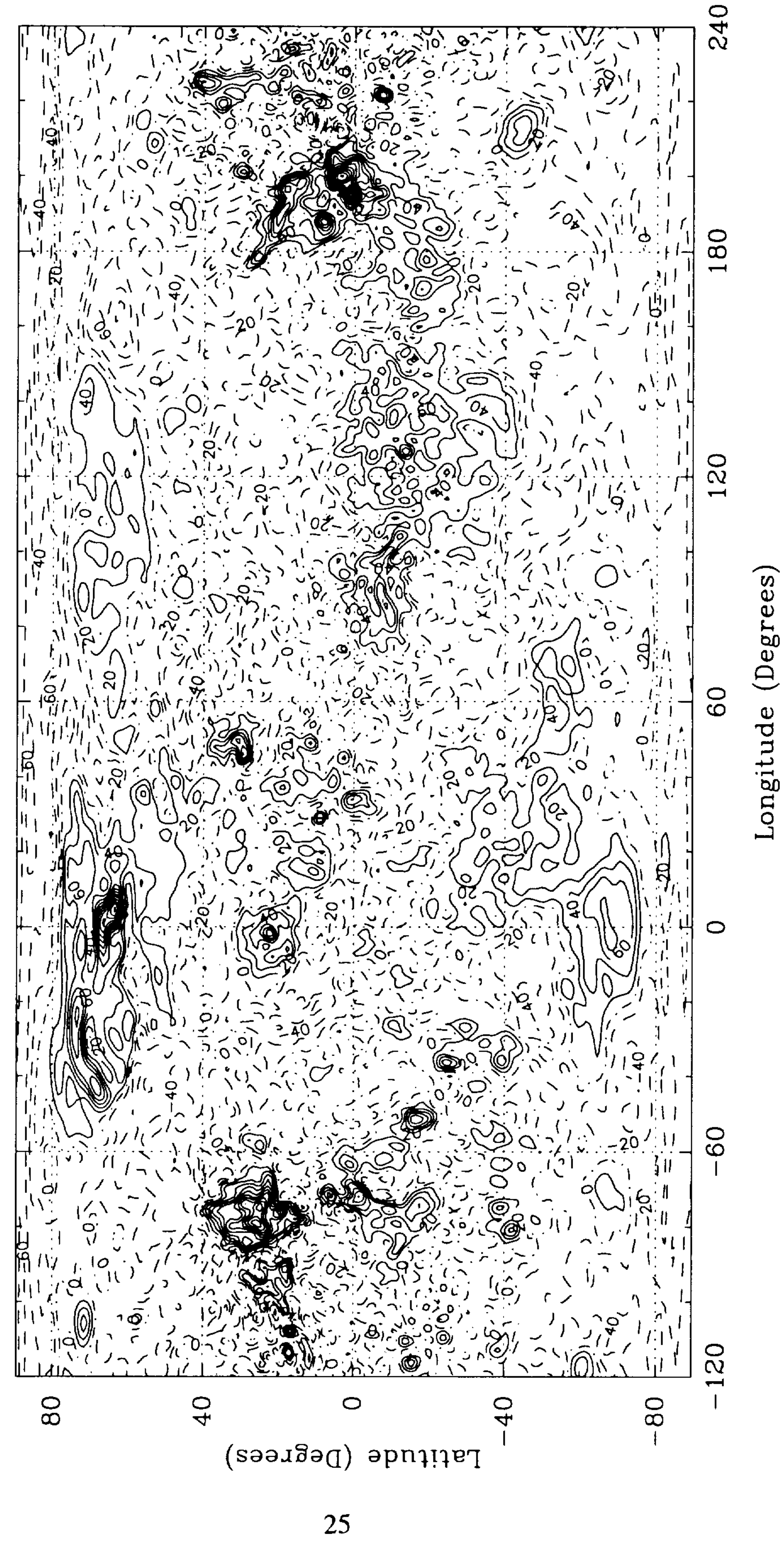


Figure 14: Geoid of Venus (meters)

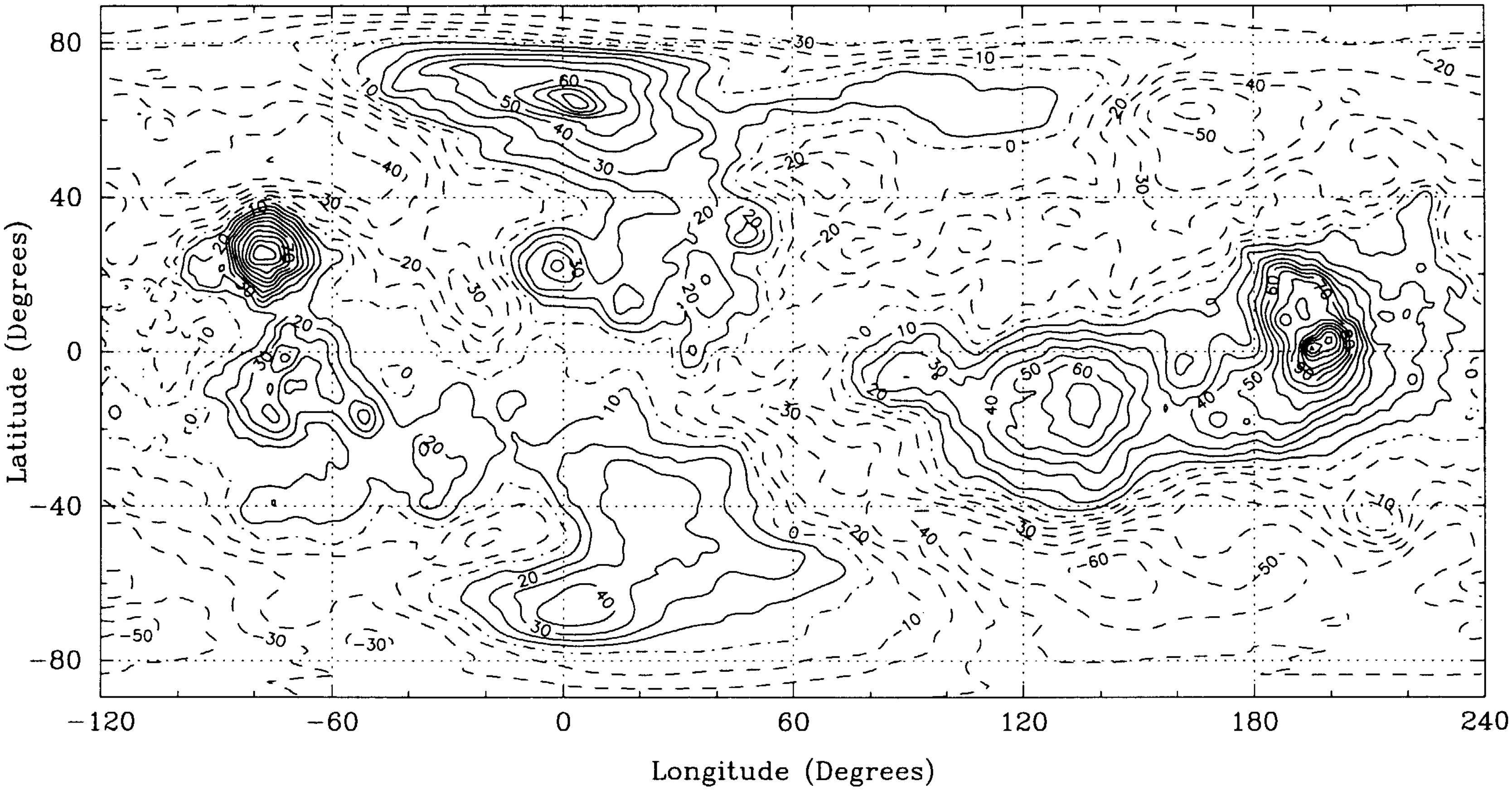


Figure 15: Vertical Gravity Uncertainty at the Surface (mgals)

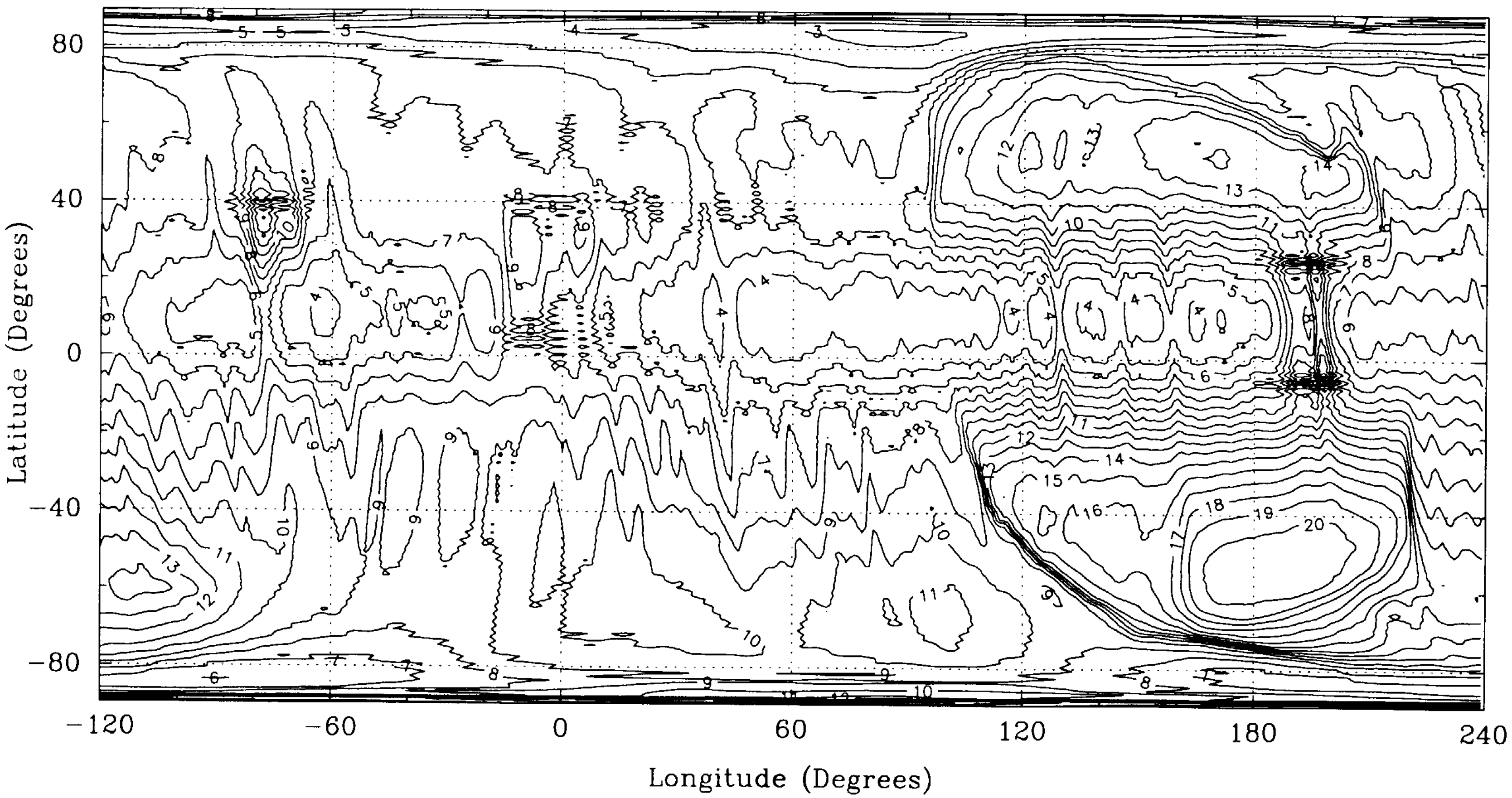


Figure 16: Venus Geoid Uncertainty (meters)

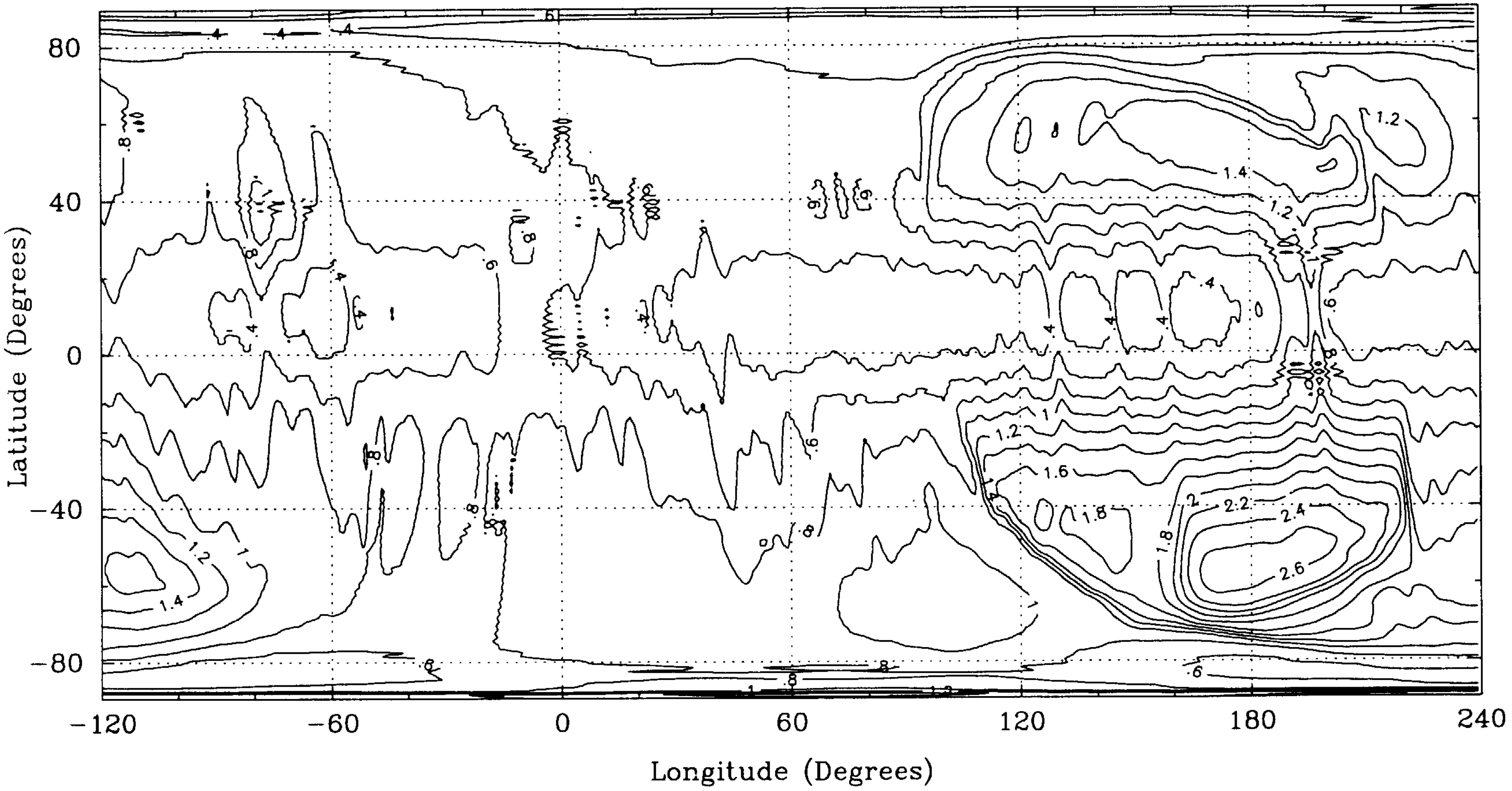


Table 5. Gravity Peaks for Venusian Features of Interest

Feature	Lon	Lat	MGNP90LSAAP	MGNP75ISAAP	MGNP60FSAAP
Maxwell	4.5	63.5	244.68	220.65	184.30
Akna	-42.5	68.5	115.17	99.57	75.52
Freya	-23.5	73.5	126.34	123.98	105.51
Bell	46.0	29.0	126.25	116.40	102.88
Beta	-79.0	25.5	234.32	231.82	211.87
Gula	-2.0	22.0	138.27	121.77	99.90
Maat	195.0	1.0	356.41	308.46	228.63
Ozza	200.0	3.5	245.52	250.75	224.63
Nokomis	190.0	19.5	132.89	136.44	124.42
Sapas	188.0	8.5	157.54	135.76	126.92
Atalanta	164.5	62.5	-84.44	-83.96	-78.34
Mead	57.2	12.6	-49.67	-39.71	-29.85

sense is globally uniform and equals about 4 to 5 milligals (the error for the sensed geoid is about 0.4 meters). After Magellan was aerobraked into a near circular orbit, there was no direct observation of the gravity field from about 160°E to 220°E, and these gaps are apparent in the uncertainty maps. The total errors (Figures 15 and 16) are largest for the southern gap in the Magellan post-aerobraking data since there the resolution is poorest and we have the greatest error from omission of higher degree terms. The largest vertical gravity and geoid errors are 20 milligals and 2.6 meters. Also visible in the error maps (and degree strength map - Figure 10), is the apoapse tracking in the cycle 5 Magellan data from about 100°E to 160°E. The face-on orbit geometry of Magellan cycle 4 data and the decrease in resolution is evident in Figure 10 near longitudes 0° and 240°E.

The degree strength map (Figure 10) can be verified by plotting the unconstrained solutions for different degree and order. The 90th degree and order solution without any gravity constraint is displayed in Figure 18 with the unconstrained solutions for degrees 75, 60, and 40 shown in Figures 19, 20, and 21, respectively. Again as in Table 4, the lower degree solutions are found by fixing the higher degree terms to the nominal gravity field (i.e. a truncation of the square root information array). The higher order coefficients (the last 5 to 10 degrees) show aliasing from signatures in the residuals due to terms with degree greater than 90. This shows up as noise in Figure 18. The 75th degree truncated solution, however, does not exhibit aliasing and is much cleaner than the unconstrained solution from MGNP75ISAAP. In general, the unconstrained solutions match the resolution map. The gravity field is completely determined to about degree and order 40 since no noise is visible in Figure 21.

The peak values of the vertical gravity for areas of interest are given in Table 5 for MGNP90LSAAP and the previous 75th degree and order solution (MGNP75ISAAP, Konopliv and Sjogren, 1994b) and 60th degree and order solution (MGNP60FSAAP, Konopliv and Sjogren, 1994a). All are maximum peak values except for the gravity lows of Atalanta and Mead Crater. The strongest gravity feature on Venus is Maat Mons, which will continue to increase in amplitude with the increasing higher degree and order gravity solutions (the next solution will be to degree and order 120). The 90th degree postfit Doppler residuals still show substantial systematic trends from the gravity for the Atla and Beta Regios. The peaks of Bell Regio show noticeable increase and also better alignment

Figure 17: Vertical Gravity Error to the Degree Strength

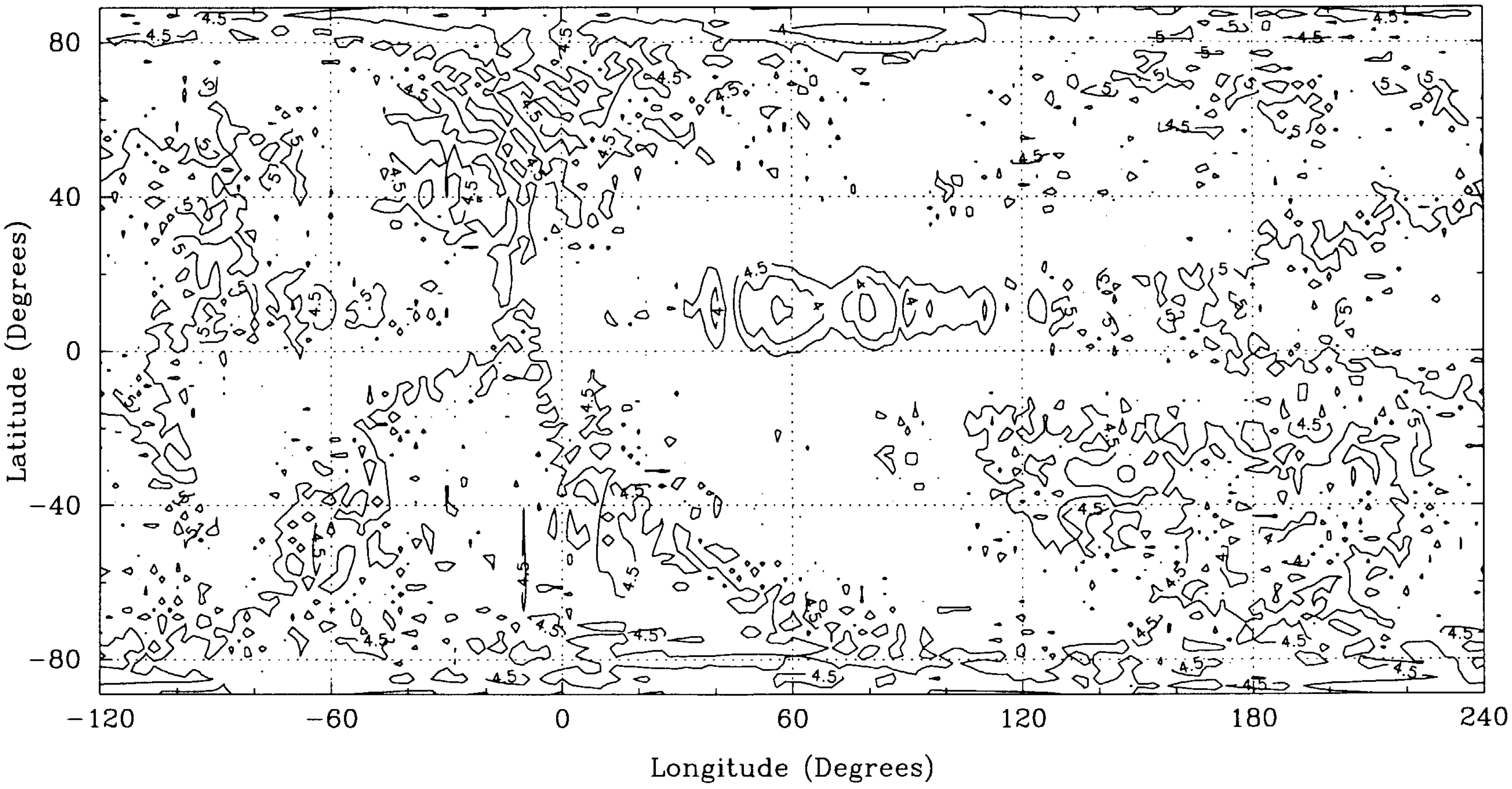


Figure 18: Unconstrained Vertical Gravity (mgals), Degree = 90

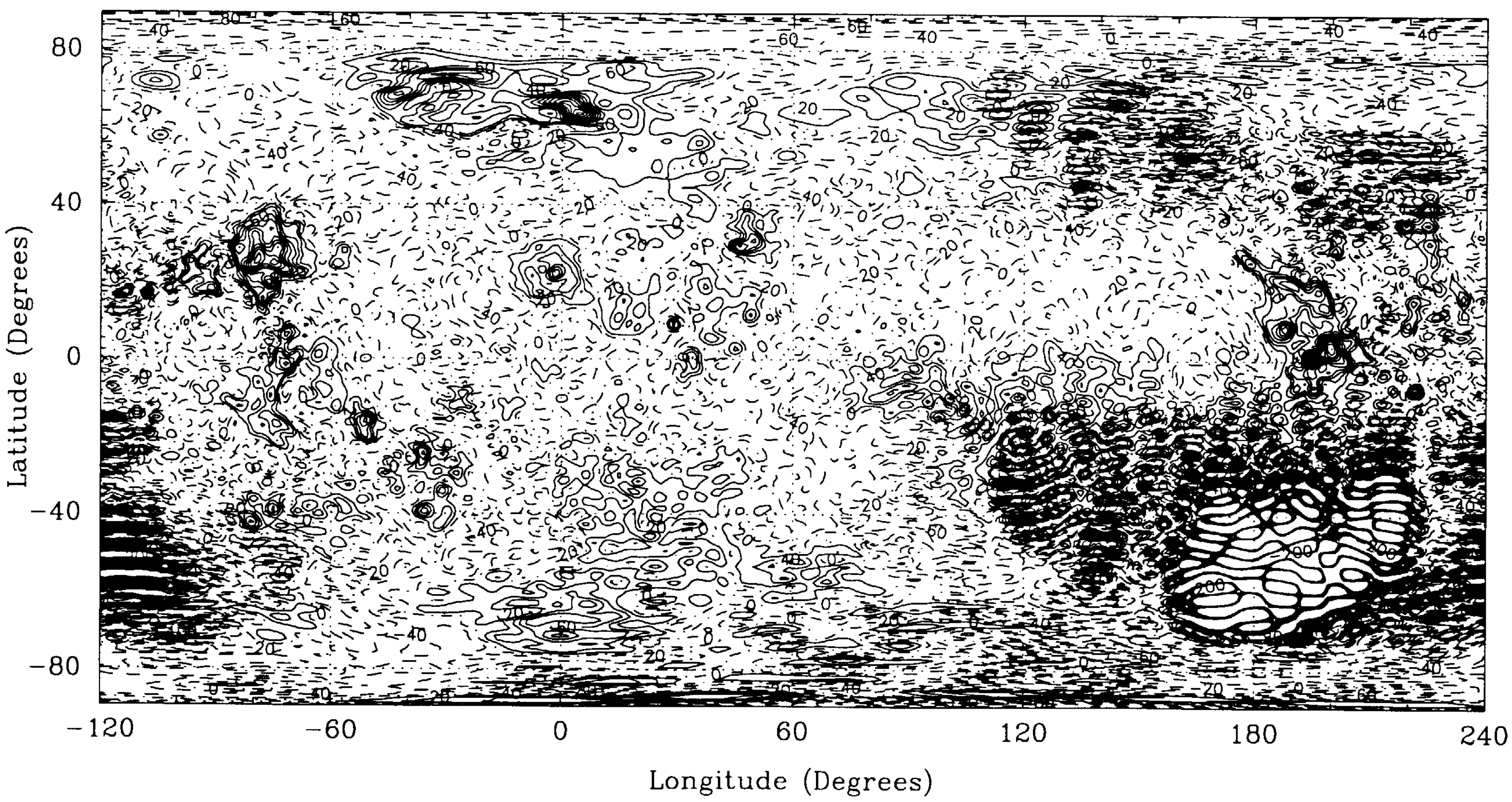


Figure 19: Unconstrained Vertical Gravity (mgals), Degree = 75

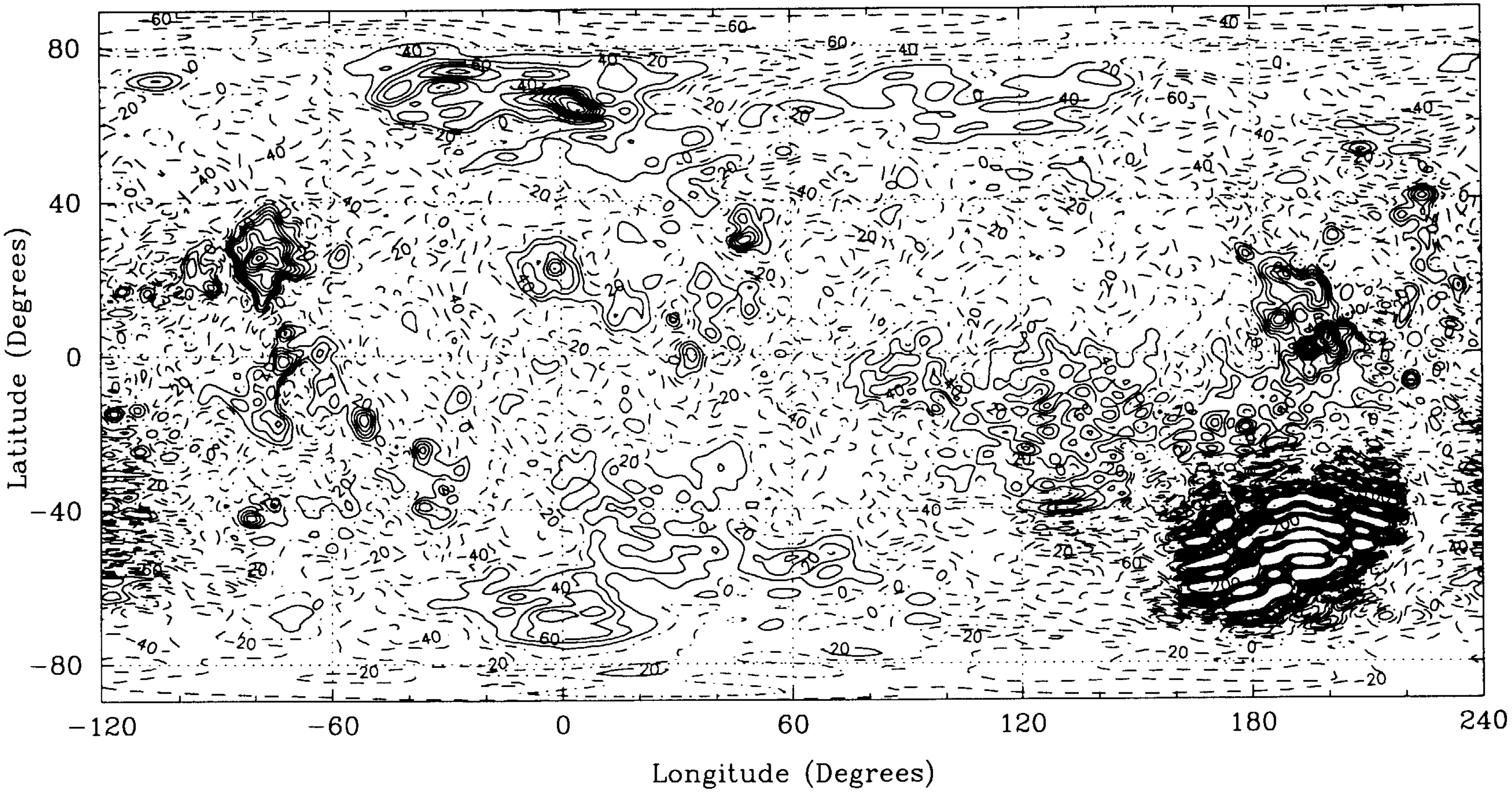


Figure 20: Unconstrained Vertical Gravity (mgals), Degree = 60

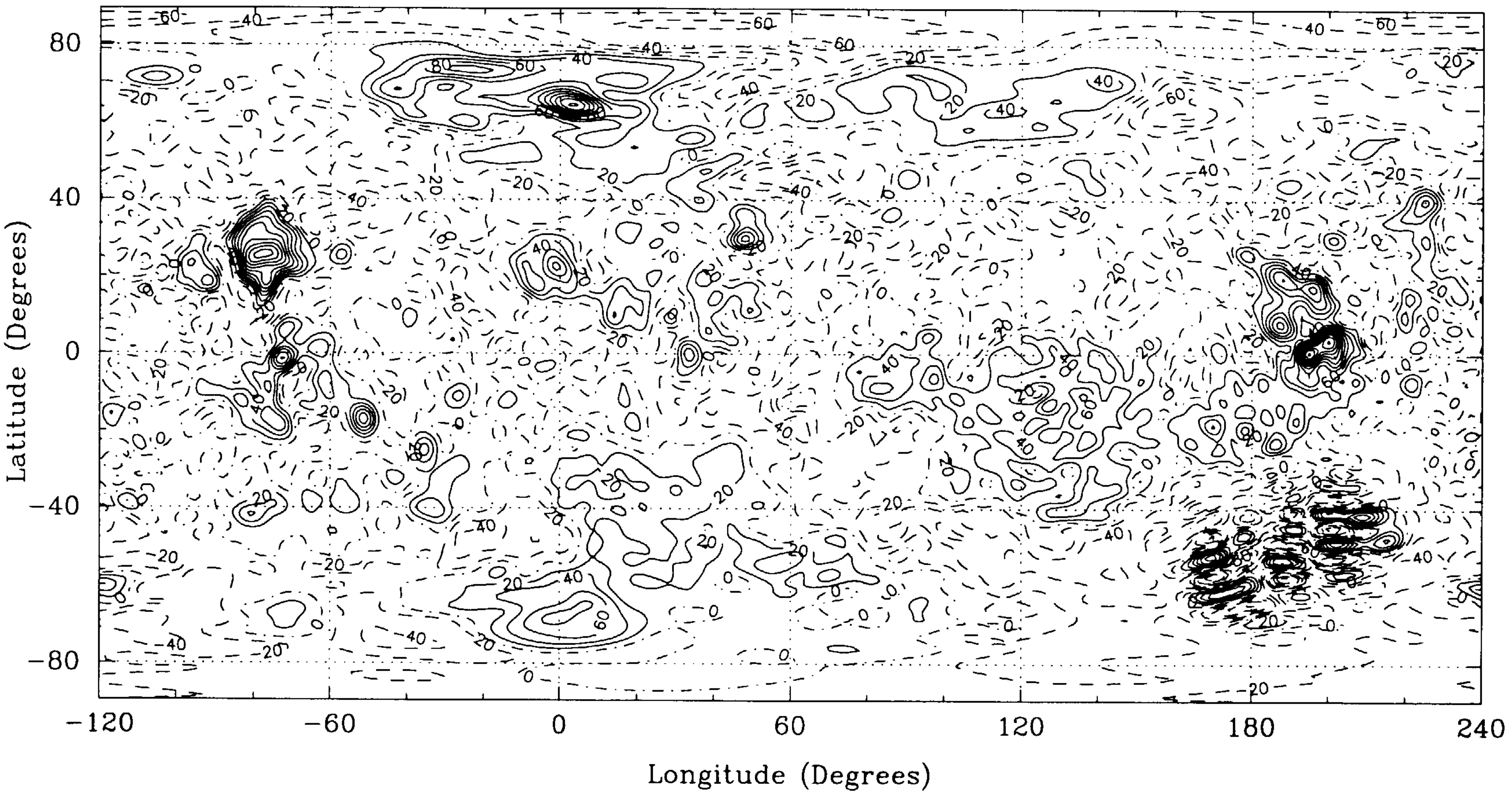


Figure 21: Unconstrained Vertical Gravity (mgals), Degree = 40

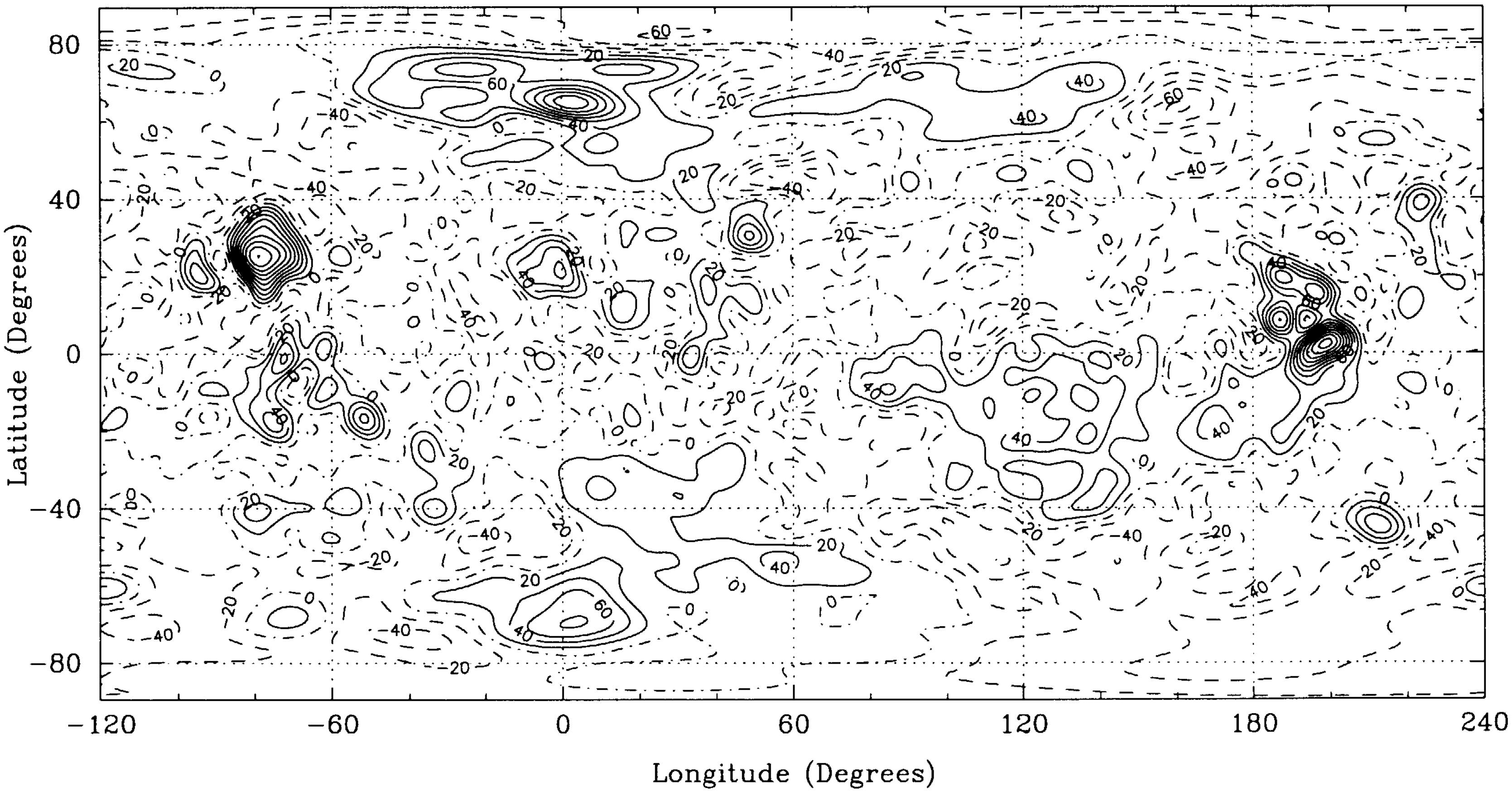


Table 6. Comparisons of Spherical Harmonics with Line-of-Sight Reductions (mgals)

Feature		Reference Altitude (km)			
Beta	Surface	187	200	250	Comments
Konopliv	234	131	128	114	
Kaula (1995)	240				2% high
McKenzie (1995)		90			31% low
Sjogren (1983)			73		43% low
Esposito (1982)			135		5% high
Smrekar (1994)				85	25% low
Maxwell	Surface	323			
Konopliv	245	68			
Kaula (1995)	200				18% low
McKenzie (1995)		39			42% low
Maat	260				
Konopliv	106				
Sjogren (1983)	64				40% low
Smrekar (1994)	75				29% low
Gula	Surface	180	202		
Konopliv	138	61	57		
Sjogren (1983)		38			34% low
Barriot (1994)	110				20% low
McKenzie (1995)			40		30% low
Smrekar (1994)			50		12% low

with the topographic highs. Appendix I contains plots of vertical gravity for different regions of Venus for MGNP90LSAAP.

A comment, which was mentioned by Sjogren (1984) when discussing his analysis of Ishtar, was that there was a need to have a positive mass placed at 51.5° N so that the acceleration profile could be fit. This gravity anomaly is now definitely revealed (see Appendix I).

A comparison of what other analysts have obtained for some of these features is shown in Table 6. They have used the line-of-sight accelerations derived from Doppler residuals and produced local estimates (all except Esposito et al, 1982, who used the raw Doppler observations and surface mass disks to estimate the Beta gravity anomaly). Most line-of-sight estimates were obtained at different reference altitudes and therefore the harmonic estimates were evaluated at those altitudes to make comparisons valid. Except for the Beta estimate of Kaula (1995, 240 versus 234 mgals), all estimates are lower than the harmonic estimates by considerable amounts. This is rather surprising since the Doppler residuals should contain the very highest resolution of the data. On the other hand, the harmonics at degree 90 leave almost no systematic signature in their residuals. An explanation for this variance may be due to the model fitting to the LOS data. The experimenters must decide on optimum block sizes or mass distributions. The data are then smoothed to avoid singularities at the surface which may reduce the amplitudes. Also, there may be amplitude reductions as a result of a larger than needed spline interval for determination of the accelerations from the Doppler residuals.

Mead was the subject of previous investigation (Banerdt et al, 1994) with a 60th degree and order gravity field. The amplitude for Mead with that model was -30 mgals with the gravity anomaly being slightly offset by about one degree from the center of the crater. The higher resolution 90th degree models show almost perfect alignment with the crater and substantially increased amplitudes, and show further confirmation that Mead is indeed mostly uncompensated (even less than the 30% maximum reported by Banerdt et al, 1994). For terms up to 90th degree, the gravity signature at the surface from uncompensated topography of Mead only and not the surrounding topography is -25.1 mgals (for up to degrees 60 and 75, the amplitudes are -9.8 and -16.7 mgals, respectively). The spherical harmonic topography model was determined by Nicole Rappaport with data from Bob Grimm and zeros out all topography except Mead. The model was determined to degree and order 120 but is truncated for comparison with the gravity. The corresponding gravity signature from Mead is also at least -25 mgals with respect to the surrounding gravity and maybe even 5 to 10 mgals larger. From degree 60 to 90, the uncompensated gravity from topography increased by 15.3 mgals and the observed gravity increases by 19.8 mgals (i.e. from Table 5). With a crust thickness of 25 and 50 km and 30% compensated, the gravity minimum from topography is -19.3 and -20.7 mgals, respectively. For the high degree terms, the uncertainty in the gravity is better than the 4 mgal formal error, and, hence, we can now say Mead is even less than 30% compensated.

The rms magnitude of the gravity spectrum for degree n (M_n) is given by $M_n = G_n/(2n+1)^{1/2}$ where G_n is the magnitude of all the gravity coefficients of degree n (given by the vector $\mathbf{G}_n$). The spectrum for MGNP90LSAAP along with the uncertainties and Kaula power rule for Venus is shown in Figure 22. Also shown is the spectrum from the unconstrained gravity solution (90lnoap or no a priori). In this case there is the same constraint on the nongravity parameters (ephemeris, pole, etc.) as MGNP90LSAAP and one can notice that the constraint on the higher degree coefficients does not affect the formal uncertainties on the lower degree coefficients (at least < degree 10, note Figures 9 and 11 show the effect of not constraining pole, etc.). From Figure 22, one can say that the gravity field is determined over the entire surface to about degree and order 40 (the crossing point of the unconstrained sigma and the Kaula power rule).

For Venus, probably the best test for evaluation of the gravity field has been the correlation with topography. As more tracking data were added to the solution and as modeling improved, the correlation with topography continued to show higher values. Figure 23 shows the correlation for MGNP90LSAAP along with the error bars. With $\mathbf{T}_n$ being the vector of all topography coefficients for degree n, the correlation for degree n is given by $\gamma_n = (\mathbf{G}_n \bullet \mathbf{T}_n)/(G_n T_n)$. The topography coefficients are given by the 360th degree and order model of Rappaport and Plaut (1994). The correlation error bars in Figure 23 for each degree ($\sigma\gamma_n$) are contributions from the gravity covariance and are given by $\sigma\gamma_n^2 = \mathbf{A}_n^T \, \mathbf{P}_n \, \mathbf{A}_n$ where the matrix $\mathbf{P}_n$ is the sub-covariance with the degree n terms ($\mathbf{G}_n$) only of the full covariance matrix of MGNP90LSAAP. The vector $\mathbf{A}_n$ is the partial of the correlation for degree n (γ_n) with respect to the gravity coefficients of degree n, $\mathbf{A}_n = (\mathbf{T}_n/G_n T_n) - \gamma_n(\mathbf{G}_n/G_n^2)$. As mentioned in Konopliv et al (1994b), the uncertainties to

Figure 22: RMS Magnitude Gravity Spectrum

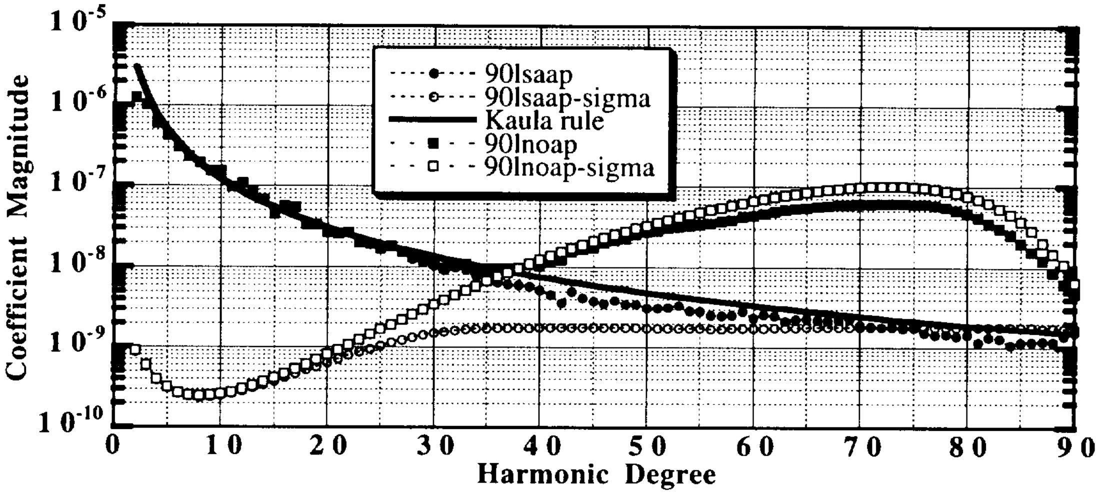


Figure 23: Correlation of Gravity with Topography and Error Bars

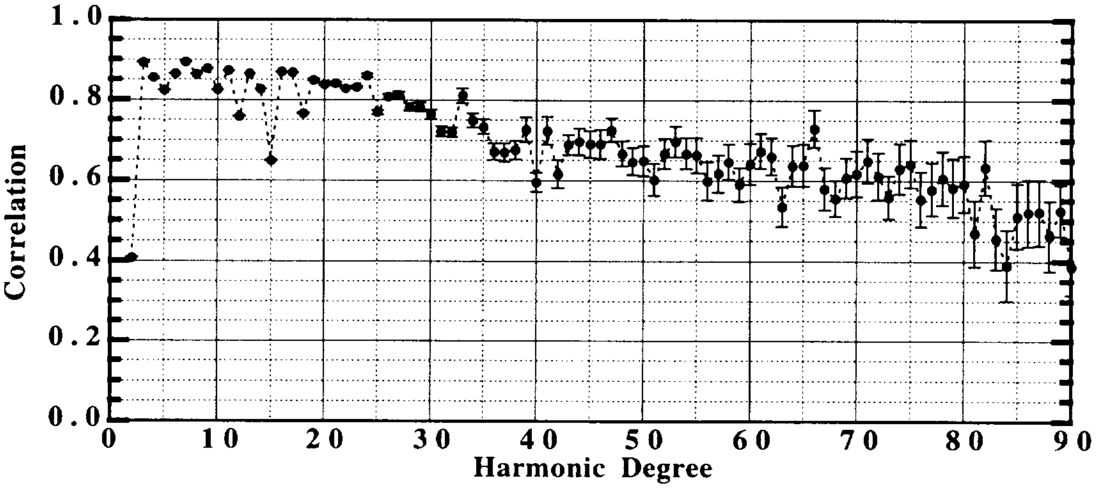


Figure 24: Comparison of Correlation with Topography for Gravity Solutions

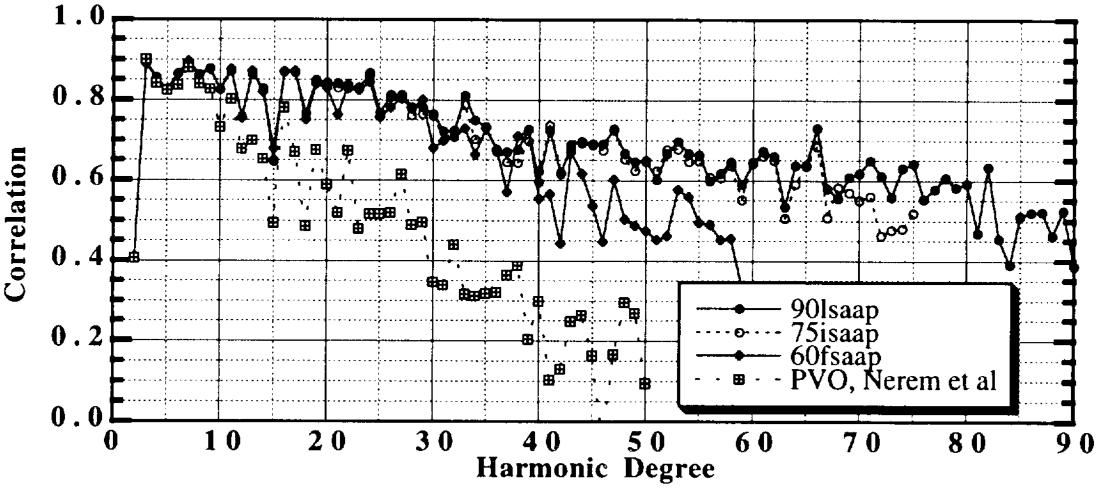


Figure 25: Correlation with Topography for N=2 to 10

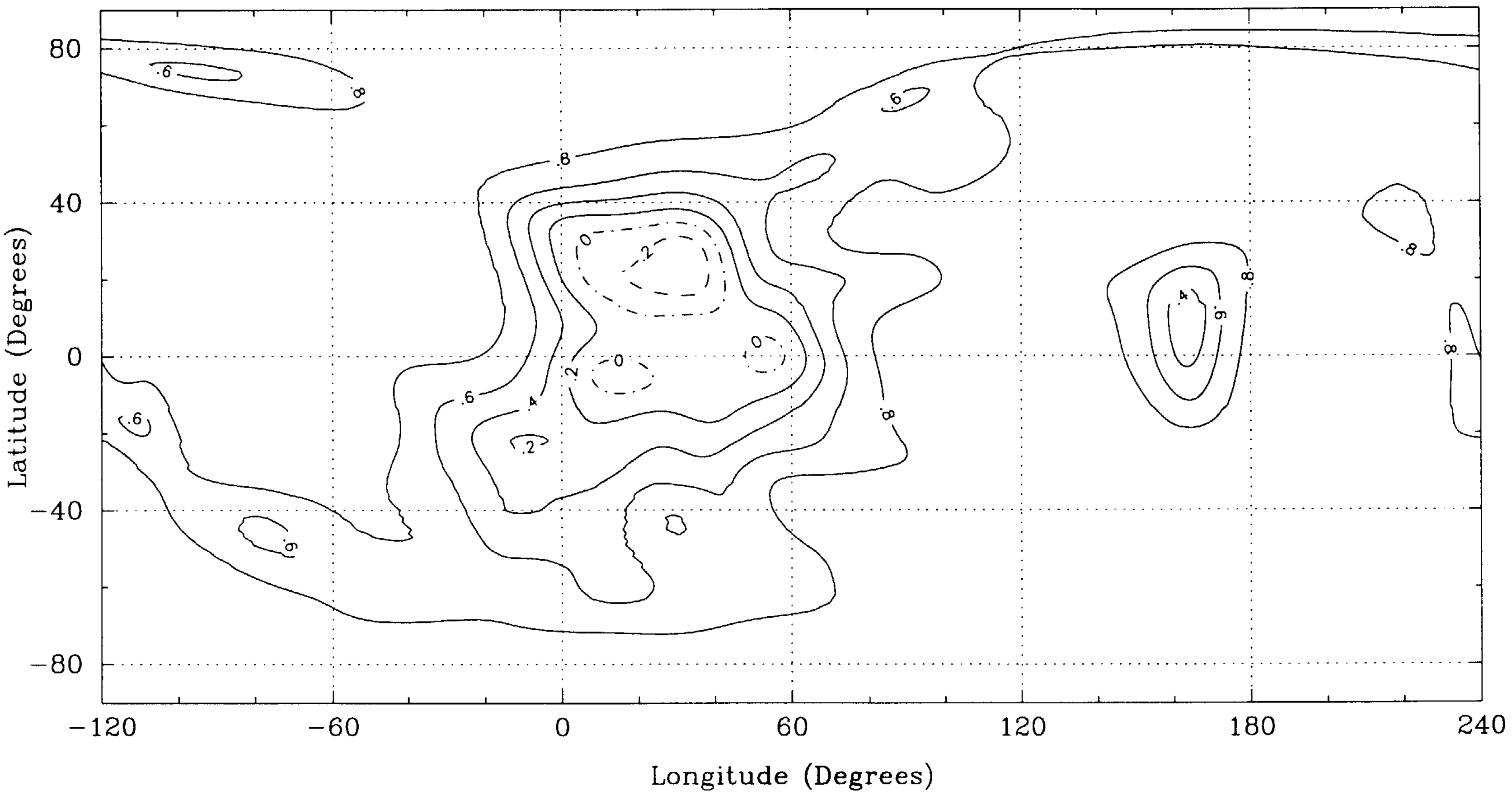


Figure 26: Correlation with Topography for N=11 to 20

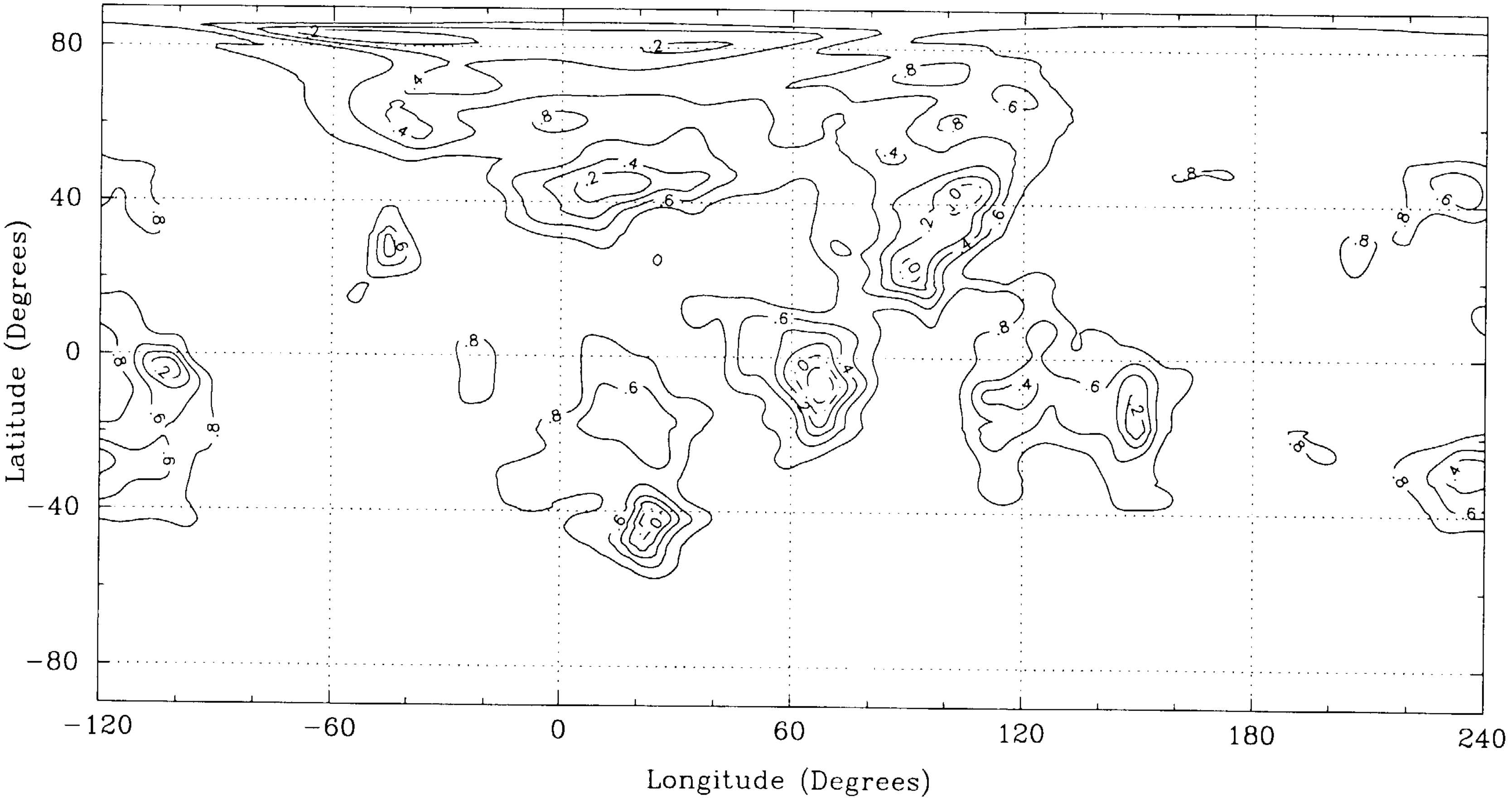


Figure 27: Correlation with Topography for N=21 to 30

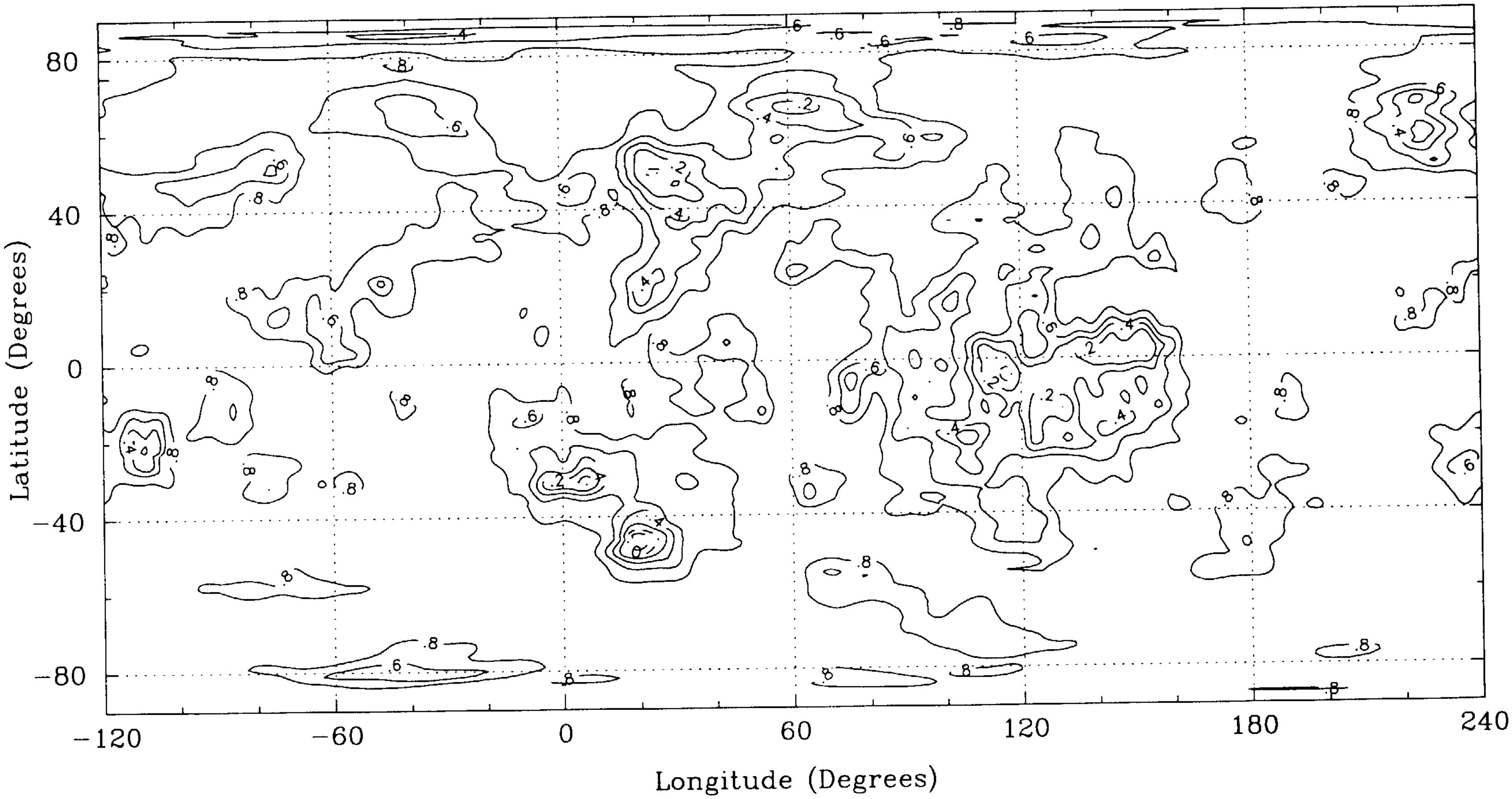


Figure 28: Correlation with Topography for N=61 to 90

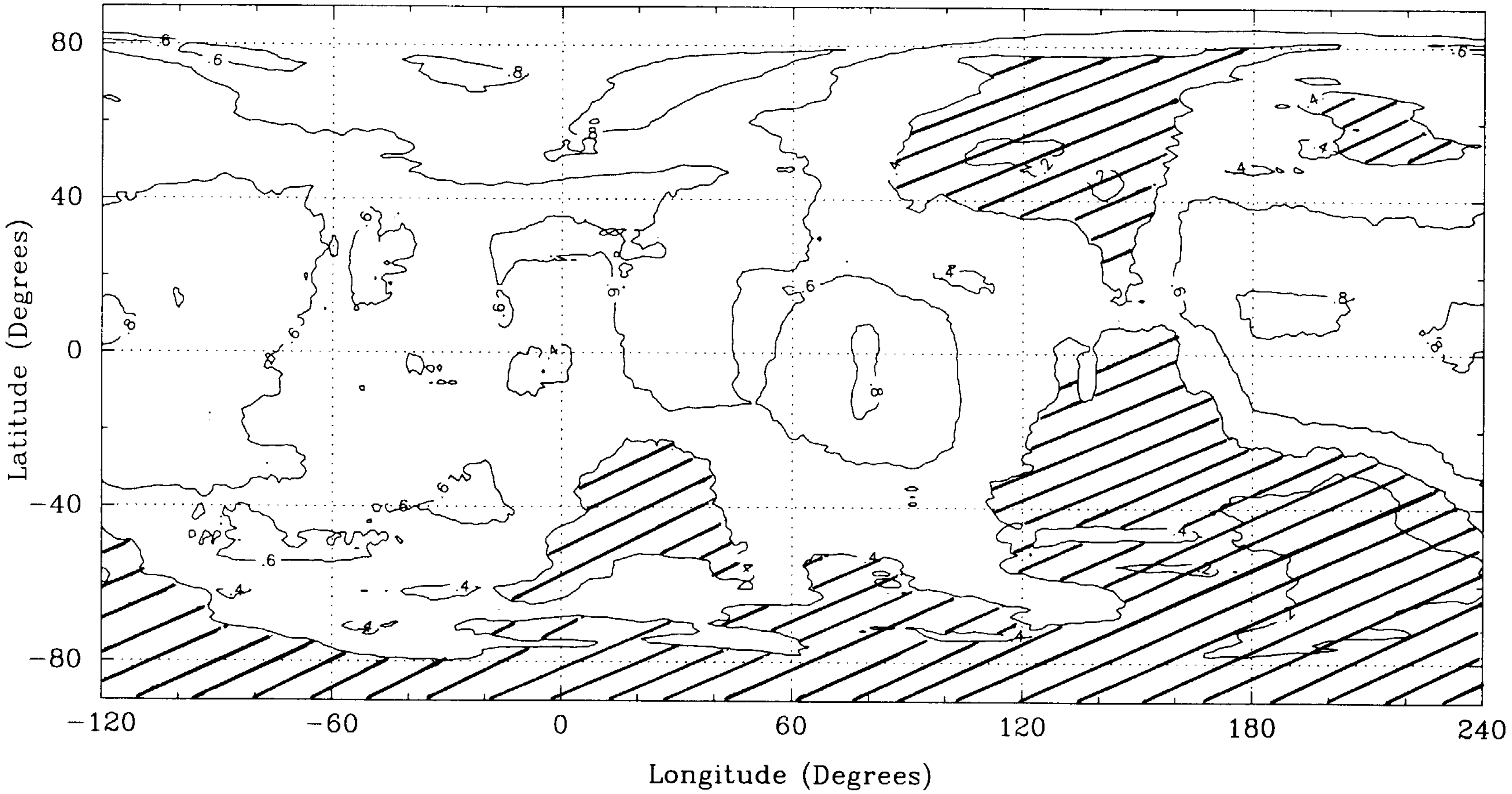
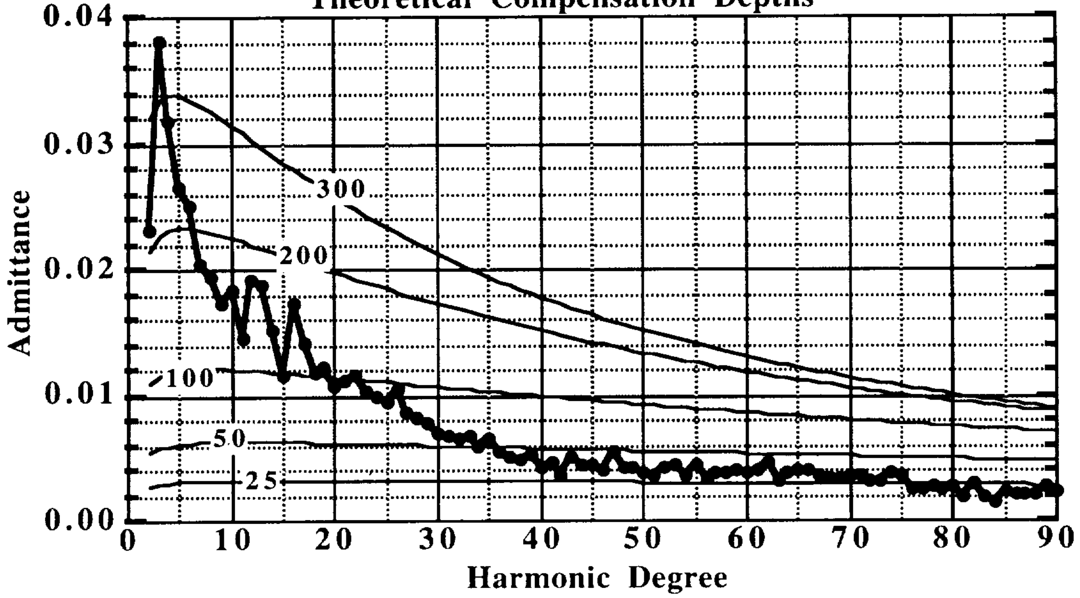


Figure 29: MGNP90LSAAP Admittance and Theoretical Compensation Depths



about degree 30 are probably dominated by uncertainties in the topography, and for degree greater than 30, the errors are mostly from gravity. Since the errors neglect the correlations between degrees, the error bars are probably optimistic. The dip in correlation at degree 15 is real and the majority of it (80%) is due to the poor correlation between the zonal coefficients. The correlations for previous solutions are presented in Figure 24. Note the increase in correlation for the last ten degrees (65-75) for MGNP90LSAAP versus MGNP75ISAAP due to the removal of aliasing in these terms for the higher degree solution.

The correlation of gravity with topography can also be plotted spatially for different ranges of degree. Figures 25, 26, and 27 show the lower degree harmonic ranges of 2-10, 11-20, and 21-30. The correlations are calculated using a sliding window equal in size to the shortest wavelength. The lowest degree harmonics (Figure 25) show a substantial mismatch between gravity and topography over Eistla Regio. The drop in correlation is mainly due to the degree two through five harmonics. In the next harmonic range, Ishtar Terra, the "claw" of Aphrodite, Tellus Regio, and Thetis Regio appear. For the higher degree harmonics (>60), one can notice a general decrease in correlations for the areas where the data are weak (see Figure 10). Figure 28 shows the correlation averaged over a 30 degree window for terms between degrees 61 and 90 with the cross-hatched areas representing correlations below 0.4. This indicates that if we had global uniform tracking coverage, the correlations for the higher degrees in Figure 23 would be greater than 0.6.

Another measure of the geophysical processes that shape the gravity and topography is the admittance between them. The admittance function for each degree n is given by $F_n = \gamma_n(G_n/T_n)$ or $G_n \bullet T_n/T_n^2$ and is displayed in Figure 29 along with the theoretical curves for apparent depth of compensation for Airy compensation. The admittance at degree n is related to the depth D by (Turcotte and McAdoo, 1979)

$$F_n = \frac{3\rho_s}{(2n+1)\bar{\rho}} \left[1 - \left(1 - \frac{D}{a_e}\right)^n\right] \tag{13}$$

where surface and mean densities are 2.9 and 5.248 gm/cm^3, respectively. The admittance, like the correlations above, can be calculated spatially for different spectral windows. Simons et al (1994) have plotted the admittance on a global scale for several different spectral windows and inferred internal processes that match the admittance. Here, we calculate the admittance for the harmonic range 40 to 60. For this range, we expect the combined effect of dynamic or thermal support for the long wavelengths and the elastic support for the short wavelengths to be minimized. With the admittance we calculate the depth of compensation on a global scale. The result is displayed in Figure 30 with averages over a 30 degree window. Assuming Airy compensation for wavelengths of degree 40 to 60, the crustal thickness is 20 to 30 km for the Ishtar and western Aphrodite regions and thicker for areas such as Atla and Beta.

The Bouguer and isostatic anomalies are also used for geophysical interpretation and are given in Figures 31 and 32. The Bouguer acceleration is the difference between the vertical gravity acceleration at the surface and the theoretical vertical acceleration from uncompensated topography. In this case, the spherical harmonic topography coefficients A_{nm}, B_{nm} are related to the theoretical gravity coefficients C^t_{nm}, S^t_{nm} for use in the potential (equation 1) by

$$C^t_{nm}, S^t_{nm} = \frac{3\rho_s}{(2n+1)\bar{\rho}} \; A_{nm}, B_{nm}$$

The large negative Bouguer anomalies for Aphrodite and Ishtar Terra are clearly evident in Figure 31. The isostatic anomaly evaluates the nonlinear difference between the gravity and topography. Given the gravity coefficients of degree n ($\mathbf{G}_n$) and the topography coefficients ($\mathbf{T}_n$), the isostatic coefficients are given by $\mathbf{I}_n = \mathbf{G}_n - F_n \mathbf{T}_n$ where F_n is the admittance. If the supporting mechanism (dynamic, isostasy) is linear, then the isostatic anomalies show the difference from the global average compensating mechanism. If for a positive anomaly, the isostatic anomaly is negative, then the feature has more compensation than the global average. If the gravity and isostatic anomalies are both positive, then there is less compensation. The small compensation of Maat Mons is clearly evident in Figure 32 as it is by far the largest isostatic anomaly. Figure 33 shows the isostatic anomaly for the Mead Crater. Since Mead is a negative gravity and isostatic anomaly, it is also much less compensated than the global average.

The stability of the solution for gravity and other parameters is given in part by the correlations in the covariance of estimated parameters. Appendix H lists the correlations between the nongravity parameters and the first degree and order five gravity coefficients. The solution in this case solves for the Venus pole and rotation. The correlations are generally fairly small with the largest correlation being 0.6. Figure 34 is a contour plot of the rms of the correlations between the coefficients of a given degree for the covariance of MGNP90LSAAP. With the a priori constraint, the correlations remain fairly small with the majority of rms values below 0.1. The correlations are a maximum for the lower harmonic

Figure 30: Apparent Depth of Compensation for N=41 to 60

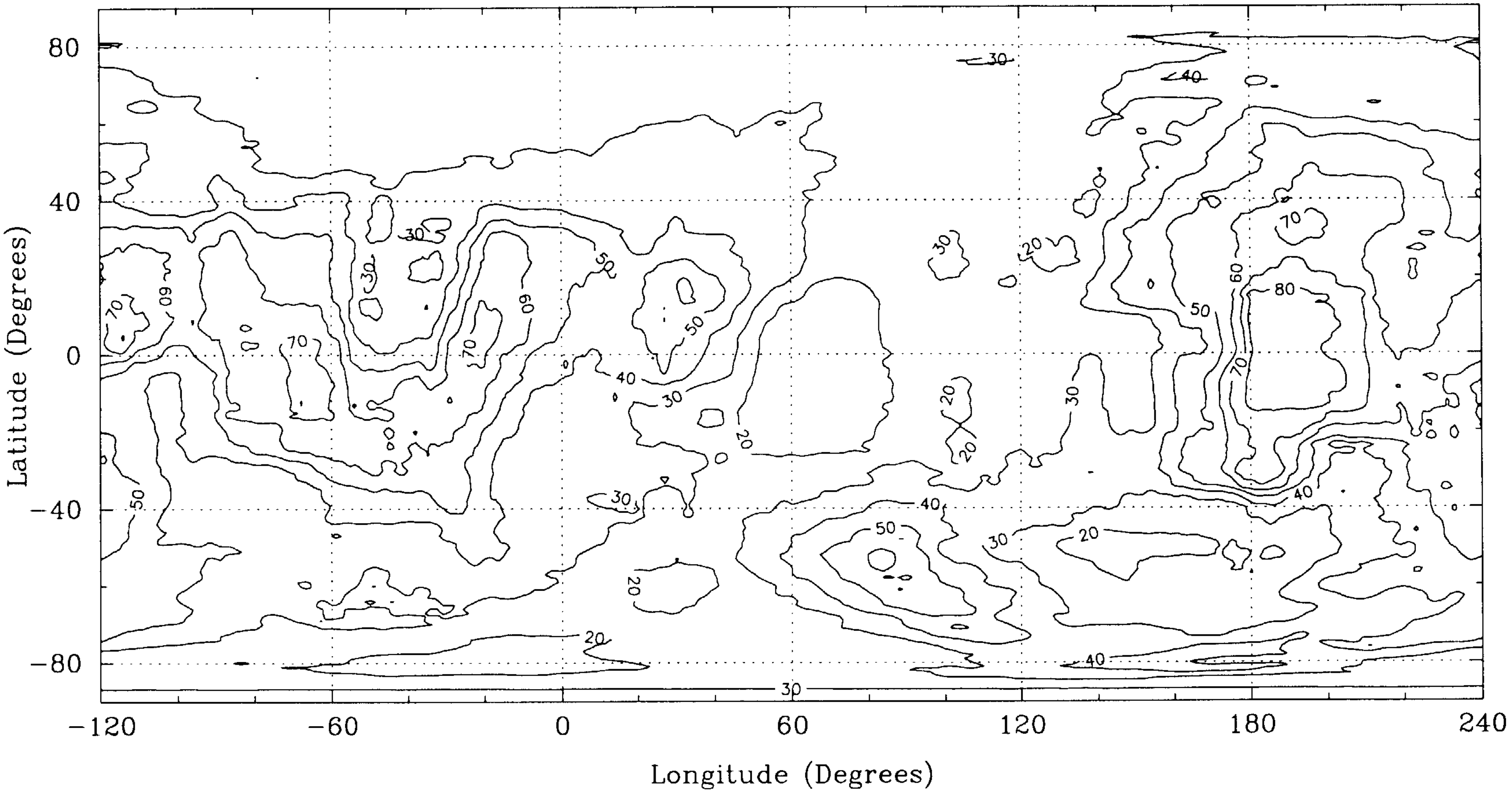


Figure 31: Bouguer Gravity for MGNP90LSAAP

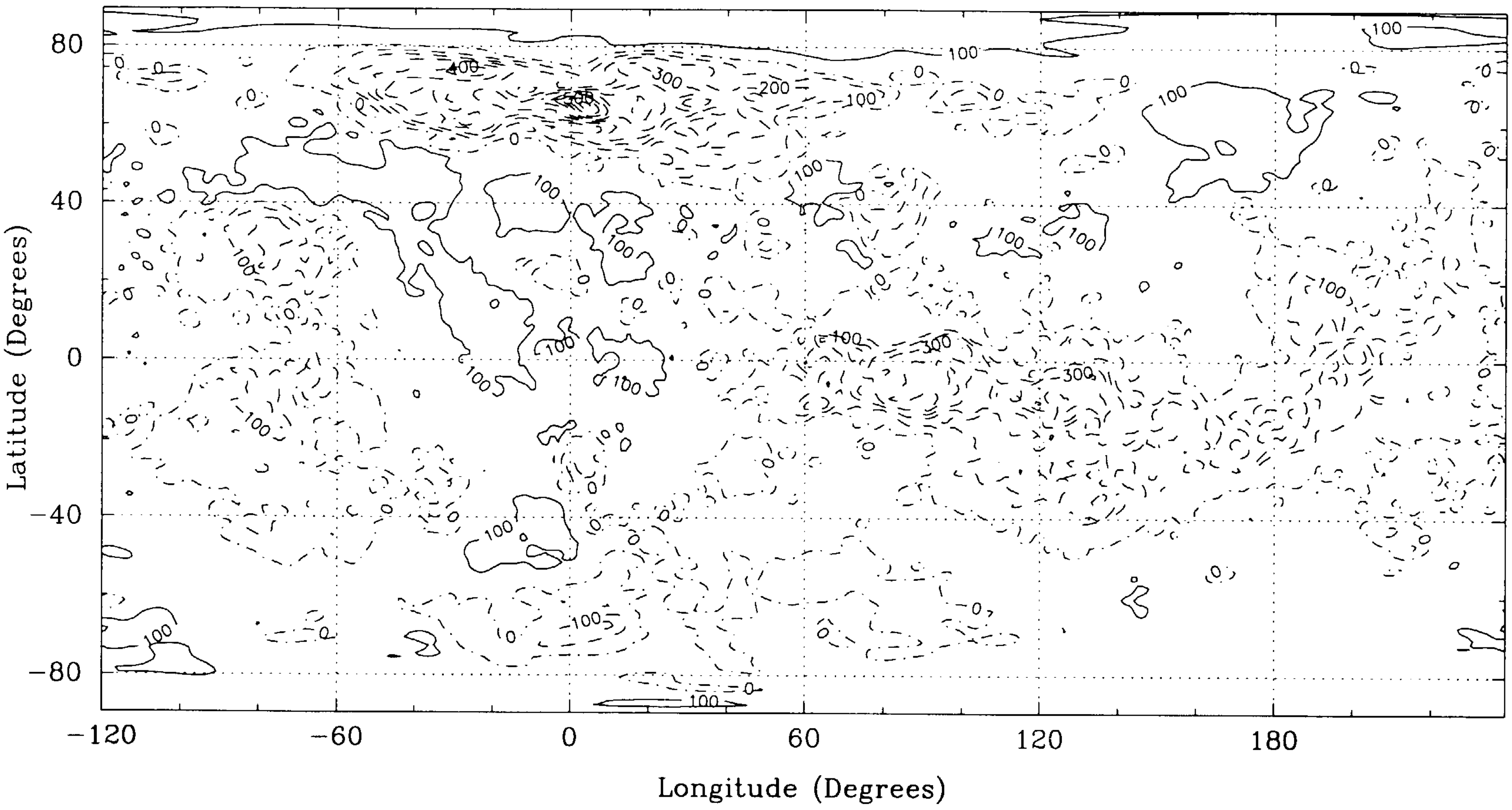


Figure 32: – Isostatic Perturbations for MGNP90LSAAP

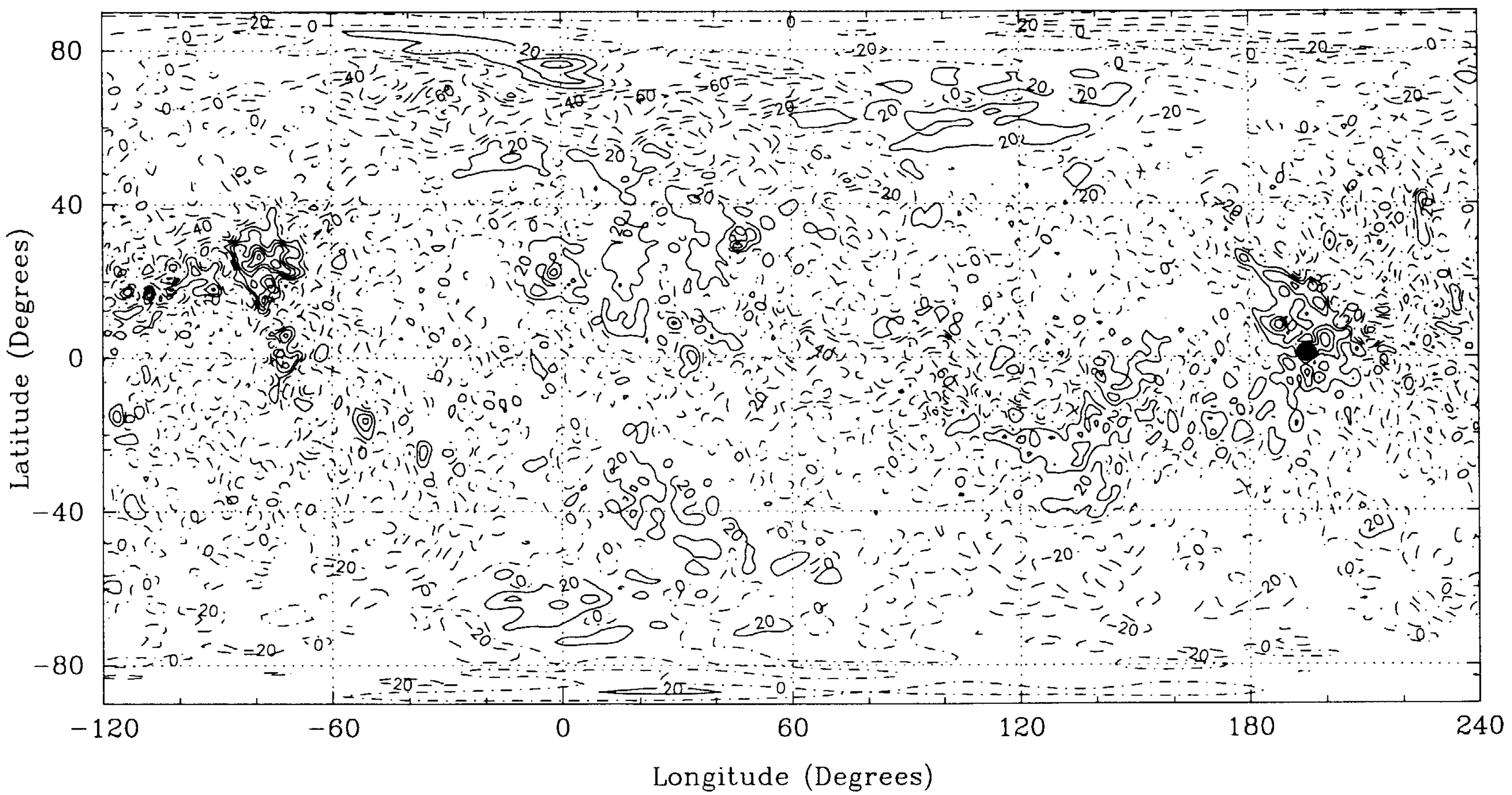


Figure 33: Isostatic Anomaly Map for Mead Crater

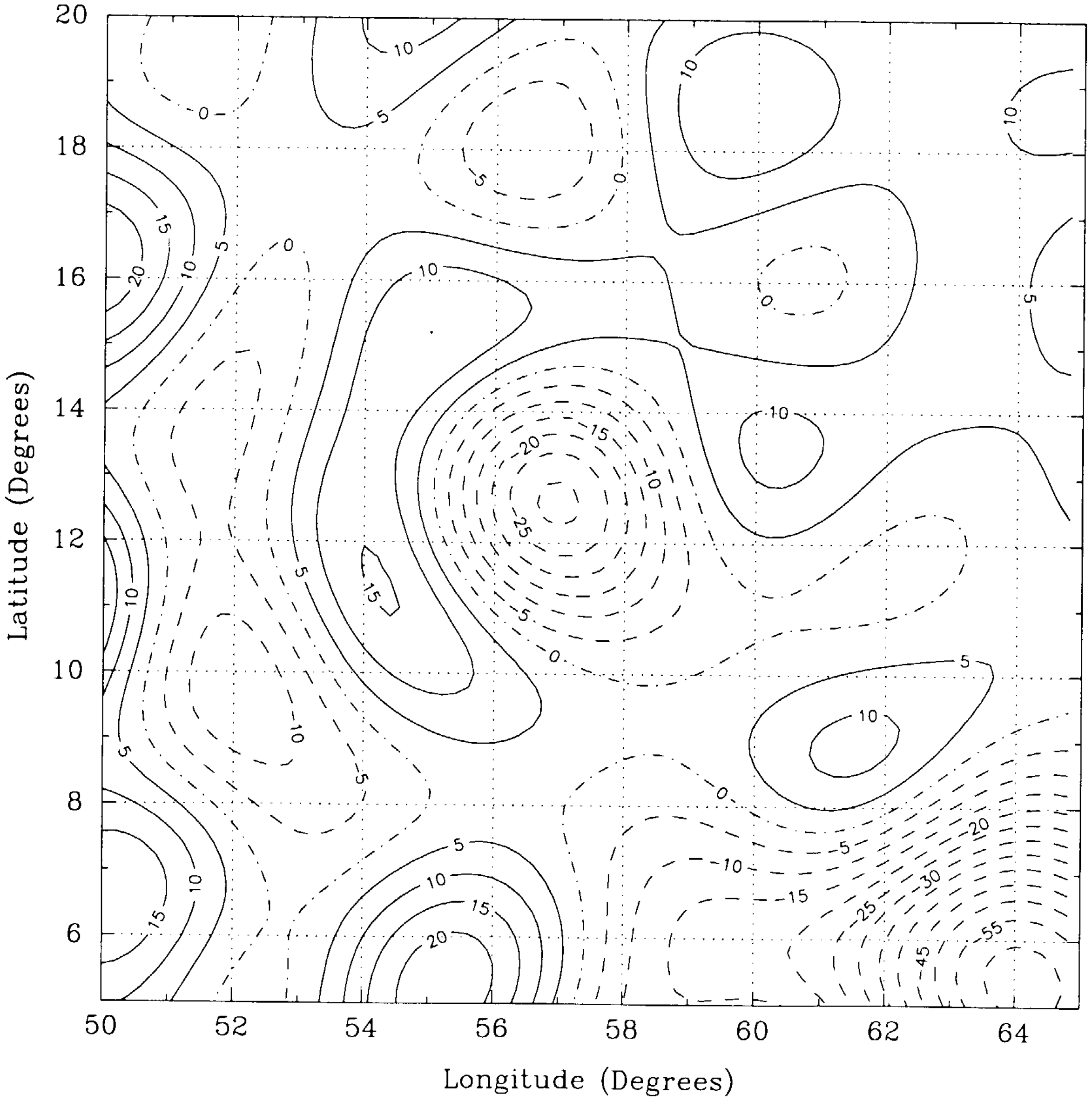
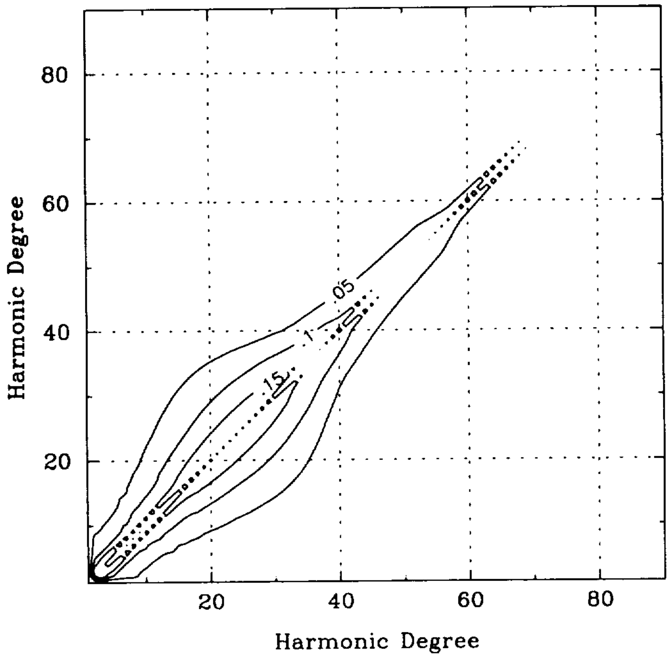


Figure 34: Gravity Coefficient Correlation Matrix



degrees and for degrees with the same approximate wavelength. We expect the correlations for the unconstrained covariance to be much greater for the higher degrees since the rms magnitude spectrum for the unconstrained spectrum is unrealistically large (Figure 22).

5b. Principal Axes

The principal axes of inertia are given by the second degree gravity harmonics. The unnormalized second degree coefficients are related to the moments and products of inertia about the body-fixed axes (1,2,3) by (Lambeck, 1988)

$$C_{20} = \frac{-1}{M_v a_e^2}\left[I_{33} - \tfrac{1}{2}(I_{11}+I_{22})\right]$$

$$C_{21} = \frac{I_{13}}{M_v a_e^2} \qquad S_{21} = \frac{I_{23}}{M_v a_e^2} \qquad (14)$$

$$C_{22} = \frac{1}{4M_v a_e^2}\,(I_{22} - I_{11}) \qquad S_{22} = \frac{I_{12}}{2M_v a_e^2}$$

where M_v is the mass of Venus and a_e the reference radius. From equations (14), the inertia tensor with the moments of inertia along the diagonal and the negative products of inertia on the off diagonals is given by

Table 7. Principal Axes for Venus in Degrees

	MGNP90LSAAP		MGNP75ISAAP		MGNP60FSAAP	
Axis	Lat	Lon	Lat	Lon	Lat	Lon
1	0.38	-3.33	0.37	-3.20	0.19	-2.89
2	0.36	86.67	0.36	86.81	0.42	87.11
3	89.48	-139.87	89.48	-139.17	89.54	-117.27

$$\mathbf{I} = M_v a_e^2 \begin{bmatrix} (I_{33}/M_v a_e^2)+C_{20}-2C_{22} & -2S_{22} & -C_{21} \\ -2S_{22} & (I_{33}/M_v a_e^2)+C_{20}+2C_{22} & -S_{21} \\ -C_{21} & -S_{21} & I_{33}/M_v a_e^2 \end{bmatrix} \tag{15}$$

From the inertia matrix, the principal moments of inertia cannot be determined because only two relationships exist between the three moments of inertia. The third relationship comes from observing the rotational behavior of the body (i.e., the precession rate). However for Venus, there has been no observation of the precession. The principal axes, however, can be determined because the eigenvectors are independent of any constant added to the diagonal elements of the inertia tensor. By setting $I_{33}=0$ in equation (15) and diagonalizing the matrix, the principal axes are determined and listed in Table 7.

Assuming a small offset ϕ of the inertial axis from the spin or z-axis, the offset in terms of the unnormalized coefficients is given by

$$\phi^2 = \frac{C_{21}^2}{(C_{20} - 2C_{22})^2} + \frac{S_{21}^2}{(C_{20} + 2C_{22})^2} \tag{16}$$

The error in ϕ is given by

$$\sigma_\phi^2 = \frac{\partial \phi}{\partial \mathbf{G}_2}^T \mathbf{P}_{G_2} \frac{\partial \phi}{\partial \mathbf{G}_2}$$

where $\mathbf{G}_2$ are the second degree coefficients and $\mathbf{P}_{G_2}$ is the covariance for the second degree coefficients. The partials are determined from equation (16). The formal sigma for the inertial offset from the spin axis is 0.01 degrees.

The pole offset to first order is given by the magnitude of the C_{21} and S_{21} gravity coefficients. Table 8 lists the normalized second degree coefficients and formal uncertainties for different data combinations. The variations are typically within three times the formal sigma except for the J_2 solution with Magellan cycle 4, which deviates from the nominal solution by eight times the formal uncertainty. Since the Magellan data are processed with only one-day arcs, the stability of the lower degree harmonics may improve

Table 8. Normalized Second Degree Coefficients with Formal Uncertainties ($x10^{10}$).

Data	Constraints	$\bar{J}_2$	$\bar{C}_{21}$	$\bar{S}_{21}$	$\bar{C}_{22}$	$\bar{S}_{22}$
P	40, K, lp	19776±48	280±48	-5±55	8569±79	-1114±76
4	40, K, lp	19932±24	320±19	173±12	8515±44	-1142±38
5	40, K, lp	19715±30	357±25	134±13	8610±24	-1016±21
P+4	40, K, lp	19799±16	289±14	160±9	8550±26	-1124±26
ALL	40, K, lp	19719±6	290±4	143±4	8543±9	-998±8
P	90, K, lp	19778±48	273±48	-15±56	8558±81	-1104±78
4	90, K, lp	19930±26	362±22	177±12	8487±46	-1091±41
5	90, K, lp	19706±35	316±30	117±14	8633±25	-1046±26
P+4	90, K, lp	19797±17	296±15	159±10	8547±26	-1113±27
ALL	90, K, lp	19718±7	291±5	145±5	8530±10	-1001±9
ALL	90, S, fp	19716±7	290±5	143±5	8547±9	-999±9

Data: P=PVO, 4=Magellan cycle 4, 5=Magellan cycle 5
Constraints: 90, 40 = degree and order of solution, K = Kaula rule, S = Spatial (SAAP)
fp = fixed IAU pole, lp = loose pole (estimated pole and rotation rate for Venus)

with increased arc lengths - the intent of future studies. Independent of the length of the data arc, the formal uncertainties for the low degree harmonics are too low as a result of the noise characteristics of the Doppler (as discussed above, i.e., it is not white noise). Using a factor of three times the formal error, the pole offset with a realistic error is 0.52± 0.03 degrees. Hence, these results give some confidence that there is a pole offset and that there is a wobble for Venus (Yoder and Ward, 1979).

5c. Love Number

The Love number is a time-varying part of the C_{22} and S_{22} coefficients as a function of the solar longitude. Since Venus rotates retrograde once every 243 days and orbits the Sun once every 221 days, the solar day on Venus is 117 Earth days. The highly eccentric PVO data include five coverages of all solar longitudes with respect to the body-fixed coordinates for the low-altitude periapse orbit and three coverages of all solar longitudes for the high-altitude PVO orbit. In local-solar-time (i.e., the longitude of the spacecraft with respect to the tidal bulge), the coverage is about one-half of the solar longitude coverage. The eccentric (cycle 4) Magellan data have two full coverages of solar longitude and the post-aerobraking data have about five full coverages of solar longitude. So multiple periods of the tidal effect are sampled by all data sets.

Table 9 gives the Love number solution (k_2) with the formal uncertainty for different data combinations as given by Konopliv and Yoder (1995c). From the 40th degree and order solution, the Love number estimate with a realistic error is $k_2 = 0.295 \pm 0.066$ (2 x formal uncertainty). This value indicates a liquid core for Venus (Yoder, 1995), although a solid core cannot be absolutely ruled out. Yoder (1995) gives a range for a liquid core of 0.23-0.29 and a value near 0.17 if the iron core has solidified.

Table 9. Love Number Solutions.

Data	Constraints	k_2
P	40, K, lp	0.230±0.244
4	40, K, lp	0.245±0.134
5	40, K, lp	0.301±0.062
P+4	40, K, lp	0.279±0.093
ALL	40, K, lp	0.295±0.033
P	90, K, lp	0.217±0.239
4	90, K, lp	0.309±0.138
4	90, K, tp	0.225±0.135
5	90, K, lp	0.337±0.070
5	90, K, tp	0.319±0.069
ALL	90, K, lp	0.320±0.035
ALL	90, S, fp	0.306±0.036

Data: P=PVO, 4=Magellan cycle 4, 5=Magellan cycle 5 and 6
Constraints: 90, 40 = degree and order of solution, K = Kaula rule, S = Spatial (SAAP)
fp = fixed IAU pole, lp = loose pole (estimated pole and rotation rate for Venus)

Future work will try to improve the Love number estimate by increasing the degree and order of the gravity field solution, increasing the length of the arcs, and improving the models of forces acting on the spacecraft. The ephemeris solution (discussed below) has shown sensitivity to the degree and order of the gravity solution and we expect the same sensitivity for the Love number. Appendix H shows that the Love number has fairly low correlations with the other global parameters with the maximum correlation being 0.31 with S_{44}. The Love number must be separated from the drag and albedo forces. The albedo force vanishes on the nightside of Venus and the drag force drops by an order of magnitude, which helps the determination of the tidal force.

6. Venus Constants

6a. Venus Ephemeris

The corrections to the Venus and Earth planetary ephemerides are estimated in the gravity solution using the Set III elements of Brouwer and Clemence (1961). The six elements for each planet are heliocentric and consist of changes in eccentricity (Δe) and semi-major axis ($\Delta a/a$) and corrections to the initial orientation of the orbit. The angle elements are $\Delta l_o+\Delta r$, Δp, Δq, and $e\Delta r$ where Δl_o is the change in mean anomaly at epoch, Δr is the rotation about the z-axis or ecliptic north, and Δp and Δq are the small rotations about the x and y axes (giving the inclination of the orbit). Table 10 lists the solutions for the corrections to the JPL ephemeris DE403 for different combinations of data. The a priori

Figure 35: Ephemeris Solution for PVO wrt DE403

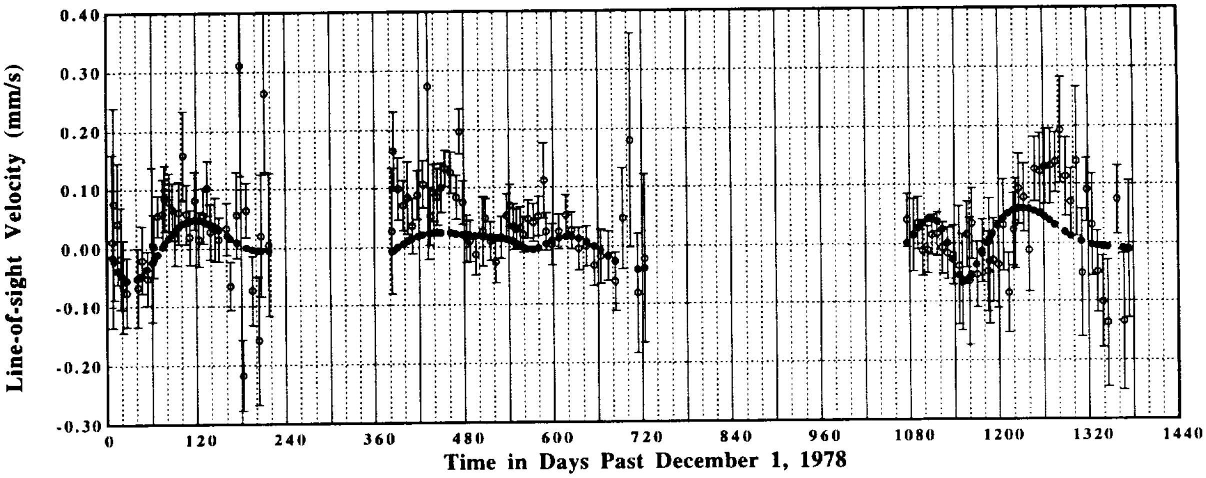


Figure 36: Ephemeris Solution for Magellan Cycle 4 wrt DE403

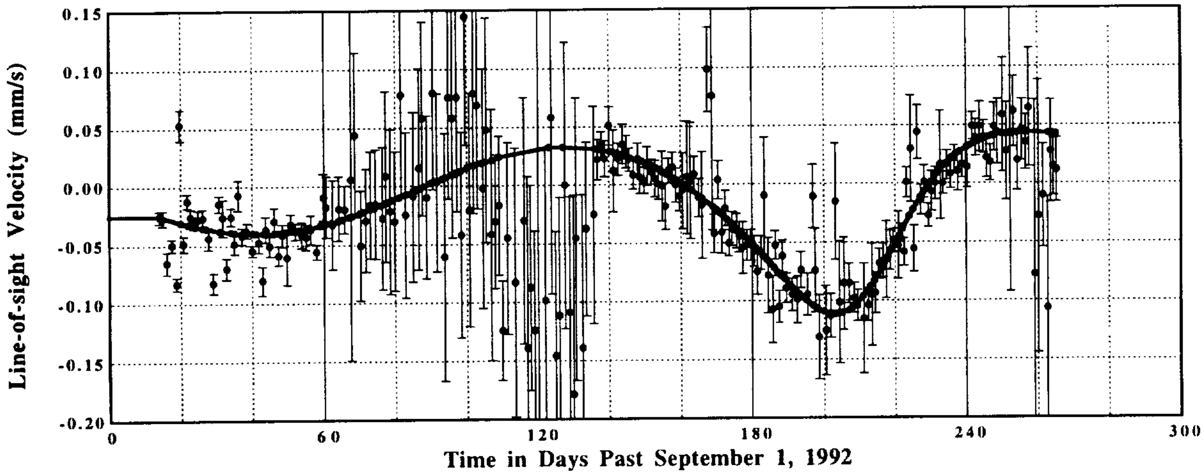


Figure 37: Ephemeris Solution for Magellan Cycle 5&6 wrt DE403

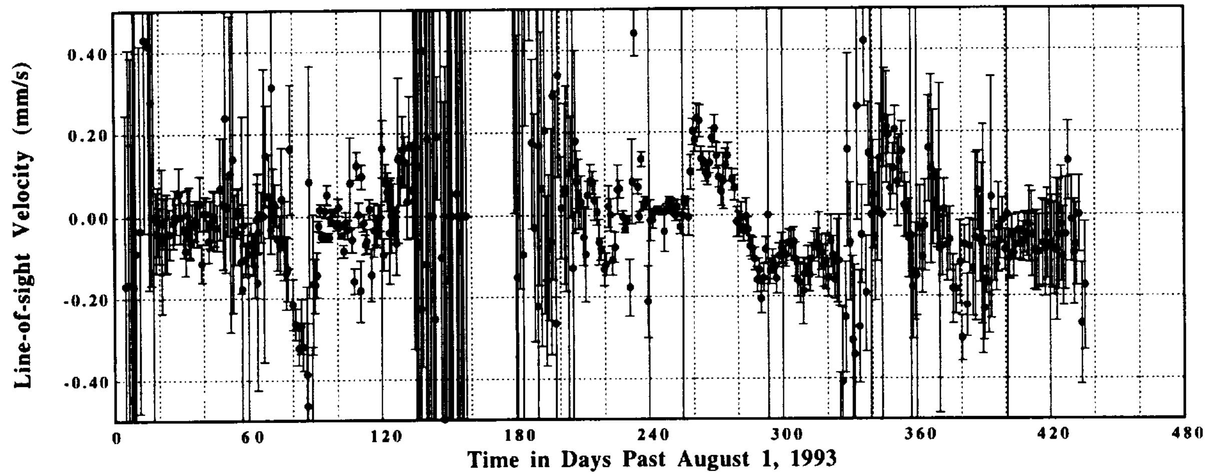


Table 10. Venus and Earth Ephemeris Solutions (x10^9).

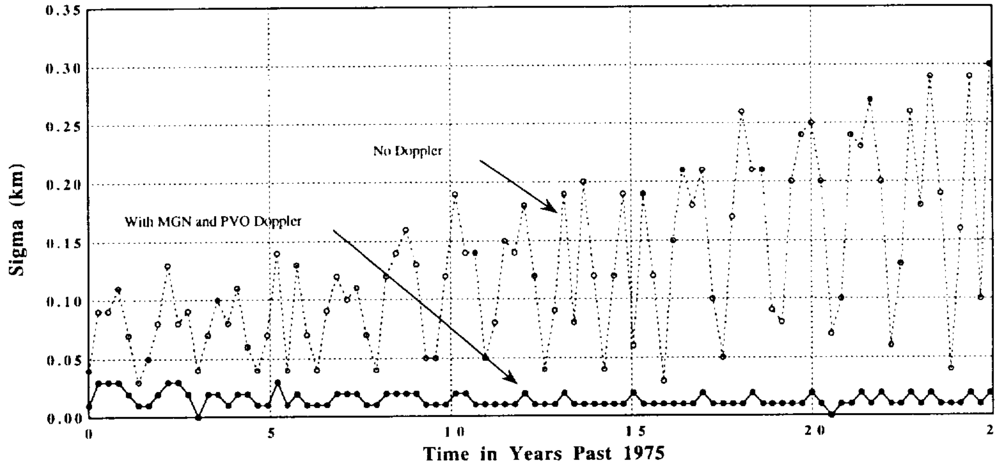
Element	PVO	MGN Cycle 4	MGN Cycle 5	MGNP90LSAAP
Venus:				
Δlo+Δr	86.5±55.3	-13.5±97.4	-141.6±84.6	-80.9±13.9
eΔr	1.5±0.4	-1.9±1.2	1.3±1.4	0.9±0.2
Δa/a	0.6±0.3	-0.2±0.3	-0.5±0.2	-0.5±0.05
Δe	-0.2±0.3	1.1±1.3	-1.0±1.3	-0.8±0.2
Δp	27.4±44.1	-77.3±21.3	-17.3±28.5	-34.9±16.3
Δq	12.8±24.6	-78.2±40.2	-33.7±43.9	-14.6±16.4
Earth:				
Δlo+Δr	81.2±53.7	52.4±90.3	-7.8±97.0	-85.8±13.8
eΔr	1.0±0.5	0.9±0.9	2.8±1.2	0.9±0.2
Δa/a	1.0±0.5	0.0±0.4	-0.2±0.4	-0.8±0.1
Δe	0.8±0.4	2.7±1.2	-0.5±0.9	0.0±0.2
Δp	23.7±39.4	-18.6±25.2	-0.2±34.6	-20.2±15.4
Δq	24.8±31.2	-93.1±39.4	11.1±37.8	-30.8±17.2

constraint on the ephemeris is zero with an uncertainty of 10^{-6} for all the elements, and this is a minimal constraint.

The correlations of the Set III parameters are given in Appendix H and indicate that the absolute longitude and semi-major axes of the Earth and Venus are highly correlated (i.e., the Venus relative to Earth position is much better determined than absolute positions). The frame tie between the planetary reference frame and the International Earth Rotation Service (IERS) is known to about 40 nrad (Folkner et al, 1994a). The element Δr is a measure of this frame tie and the offset (80nrad) is greater than a realistic offset. This large value is due in part to the Magellan cycle 5 data (the value drops to 40 nrad without cycle 5 data) and the corrupting influence of higher order terms in the gravity field.

The Doppler data contain ephemeris information and this becomes more obvious when the relative velocity between the Earth and Venus (i.e., a Doppler bias) is estimated for each data arc (the MGNP90LSAAP gravity field is used and no global parameters are estimated). Figures 35, 36, and 37 show the solution for the Venus-to-Earth relative velocity with respect to DE403 for PVO, Magellan cycle 4, and Magellan cycle 5 and the formal uncertainties are given as error bars. The biases for the PVO data (Figure 35) are very sensitive to the ionospheric calibrations. The ionospheric calibrations for the high-altitude PVO data were not available for the generation of MGNP90LSAAP, but were for the solution of the Doppler biases. Plotted with the Doppler biases is the ephemeris solution. It was generated by Standish (private communication, JPL, 1995) using all the existing data for DE403 along with the Doppler biases for PVO and Magellan cycle 4 as observations (Magellan cycle 5 was not included due to systematic trends in the bias observations that are obviously not due to the ephemeris). The corrections to the initial state of Venus and Earth absorb the systematic trend in the Magellan cycle 4 data and some of the trends in the PVO data. The trend at 0.10 mm/s is determined to about 0.02 mm/s as given by the scatter in the bias solutions. The cycle 5 bias solutions contain trends that are

Figure 38: Venus wrt Earth Radial Position Error



most likely due to the higher than 90 degree field since the bias increases correspond to periapse passage over the Atla Regio and apoapse passage over Beta Regio (after apoapse was lowered). Figure 38 displays the errors in the Venus relative to Earth ephemeris in the solution by Standish. The errors have been reduced from hundreds of meters to tens of meters. Increased arc lengths (3 days plus) should help in determination of the Doppler bias since this will help average out the signature of the Earth's rotation in the Doppler.

6b. Venus Pole and Rotation

The Venus spin pole and rotation rate are fixed to the IAU 1991 values for the formal delivery of the MGNP90LSAAP gravity solution. However, solutions of the pole and rotation rate are determined along with the gravity field and other global parameters. Table 11 lists the solutions for different data combinations. The pole location is given by the right ascension and declination of the pole in the Earth mean equator at epoch J2000 coordinate system. The IAU 1991 values are used as the a priori values with an uncertainty of 0.05 degree for the pole and 0.005 day for the rotation rate. For all but the final solution, the pole rate along with the position was estimated. The a priori on the pole rate is zero with an uncertainty of 0.05 deg/century (about the expected amplitude for the Venus precession rate, Yoder 1995). The pole rate is not well enough determined to give a precession rate but estimating it gives a marked increase in the formal statistic due to the almost 1.0 correlation between the pole position and rate in the covariance matrix.

Increasing the formal statistic by a factor of three, the pole solution is 272.749±0.003 degrees for the right ascension, 67.160±0.003 degrees for the declination, and 243.0194±0.0006 days for the rotation rate. Our rotation period solution is slightly longer than that determined by Davies et al (1992b) of 243.0185 ± 0.0001. Both, however are consistently below the 1988 IAU value (243.025) based upon Earth radar measurements of Venus and more recent radar determinations by Slade et al (1990) of

Table 11. Venus Pole and Rotation Rate Solutions

Data	Constraint	Right Ascension	Declination	Rotation Rate
P	90,K,rate	272.735±0.047	67.194±0.040	243.0192±0.0014
4	90,K,rate	272.779±0.027	67.115±0.012	243.0204±0.0019
5	90,K,rate	272.759±0.004	67.160±0.003	243.0189±0.0010
P+4	90,K,rate	272.789±0.015	67.162±0.008	243.0201±0.0004
ALL	90,K,rate	272.751±0.003	67.152±0.003	243.0192±0.00024
ALL	90,S,no rate	272.749±0.002	67.160±0.001	243.0194±0.00018

243.022 ± 0.003. The pole solution from Davies et al (1992b) is 272.76±0.02 for the right ascension and 67.16±0.01 for the declination and these solutions agree well within the error bars.

7. Solutions for Auxiliary Forces

The auxiliary forces consist of solutions for the atmospheric drag, solar pressure, Venus albedo, Magellan momentum wheel desaturations, and Magellan hide information. The two most important forces (the drag and solar pressure) are addressed below. The solution trends for the other forces (mostly momentum wheel desaturations) have not been investigated in detail but will be checked for future models.

7a. Atmospheric Drag

PVO with its high velocity through periapse (9km/s) and 24 hour period provides an excellent measure of the atmospheric density. Using the VIRA scale height profiles, the solutions for the PVO densities are mapped to a constant altitude of 140 km in Figure 39 with the error bars also given (the error bars are generally so small that they are not visible). The densities on the nightside of Venus are generally an order of magnitude smaller than the dayside. The PVO spacecraft passes through periapse from north to south with the antenna leading. The axis of symmetry for the cylinder has an angle-of-attack of 22 degrees at periapse. A drag coefficient of 2.2 is used and at the given angle of attack the cross-sectional area of the cylinder is 5.858 m^2. The mass history was used for PVO and began at 362 kg and was 343 kg at the end of the low-altitude PVO coverage. These spacecraft values provide excellent agreement with the VIRA atmosphere model and this is not surprising since the VIRA model is, in part, based upon the PVO drag measurements (Keating et al, 1985). The differences with the VIRA model are displayed in Figure 40.

The solution for the lift-to-drag coefficient $C_{l/d}$ (one per arc) versus LST is given in Figure 41. At this point, not much can be said about the magnitude of the lift except that the correct direction is being determined. For PVO, the expected values are 0.015 to 0.044 for an accommodation coefficient of 1.0 and 0.182 to 0.195 for 0.8 (D. Rault, private communication, Langley Research Center, Aerothermodynamics Branch, 1995). For now, the lift coefficient is constrained to zero with an uncertainty of 0.05. If the uncertainties are

Figure 39: PVO Low-Orbit Density Solution at 140 km Altitude

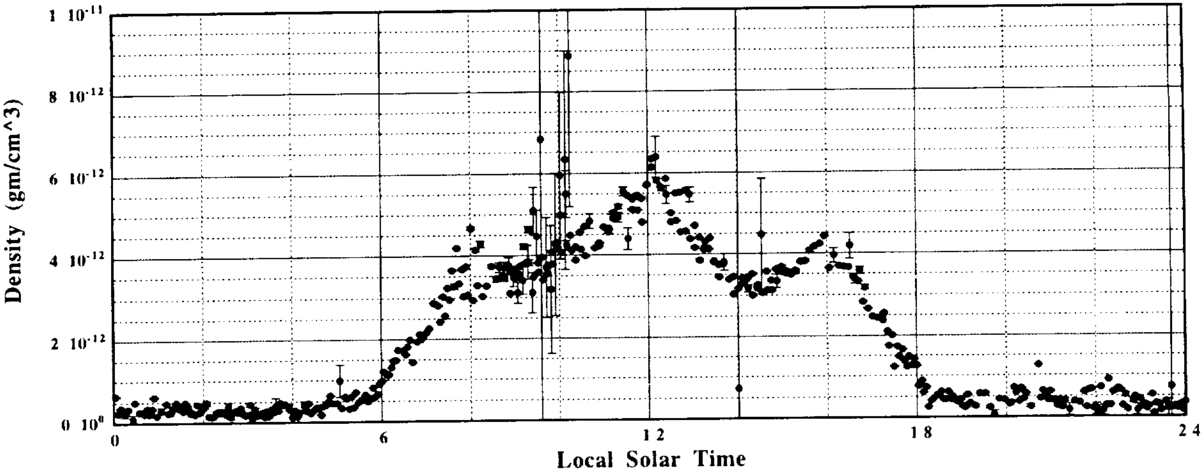


Figure 40: Difference of PVO Density Solutions and VIRA Values at Spacecraft Altitude

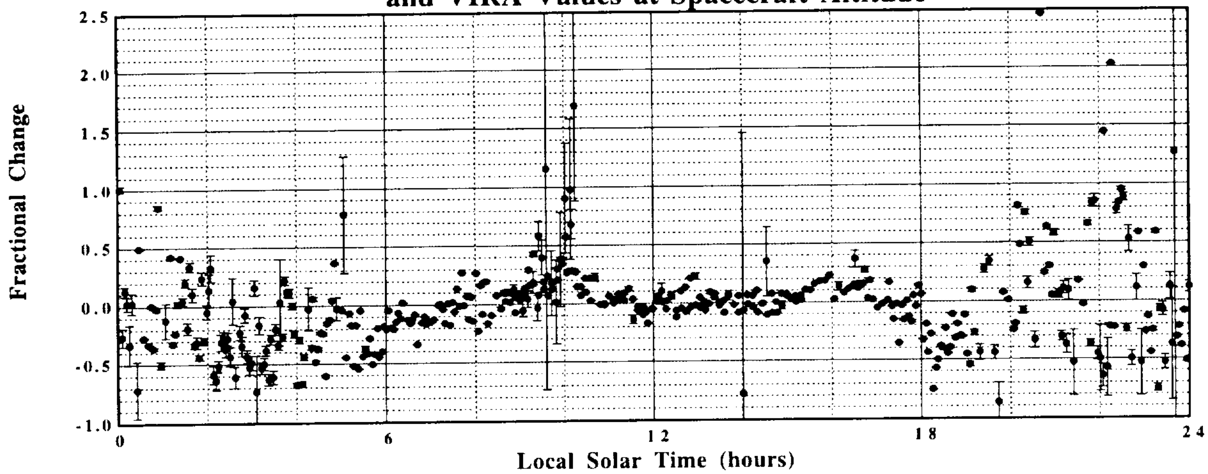


Figure 41: PVO Low-Orbit Atmospheric Lift Solution

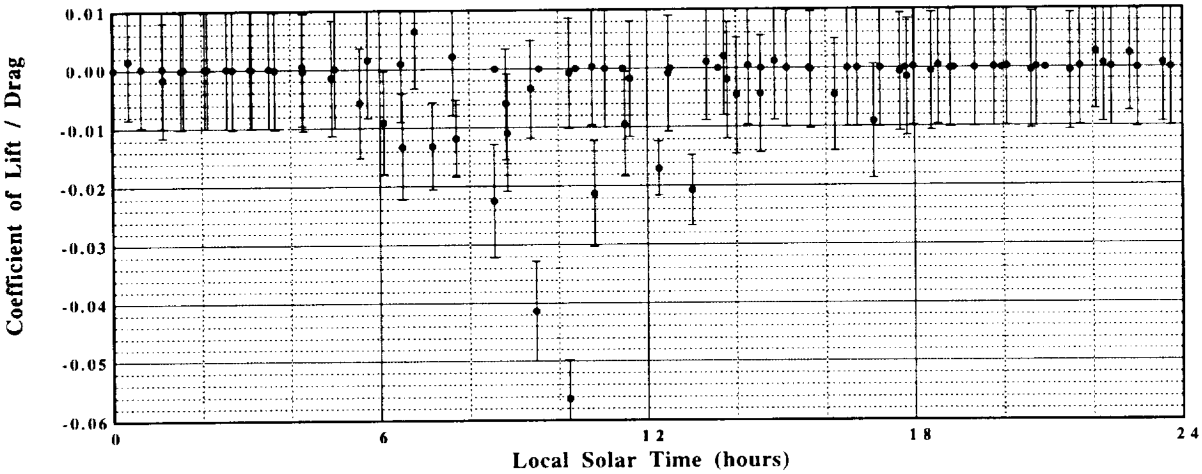


Figure 42: PVO Low-Orbit Solar Radiation Pressure (GR) Solution

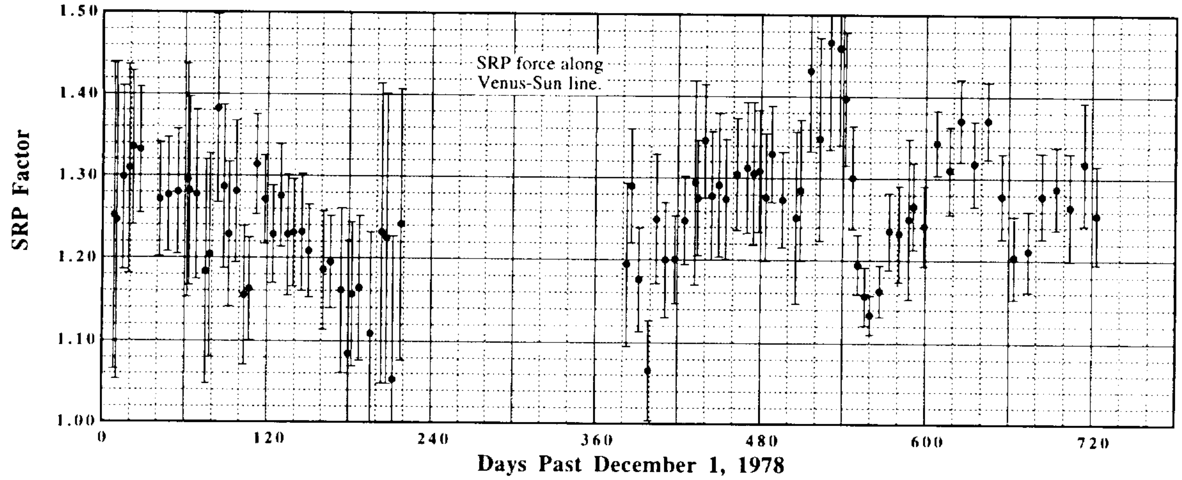


Figure 43: PVO Low-Orbit Solar Radiation Pressure (GX) Solution

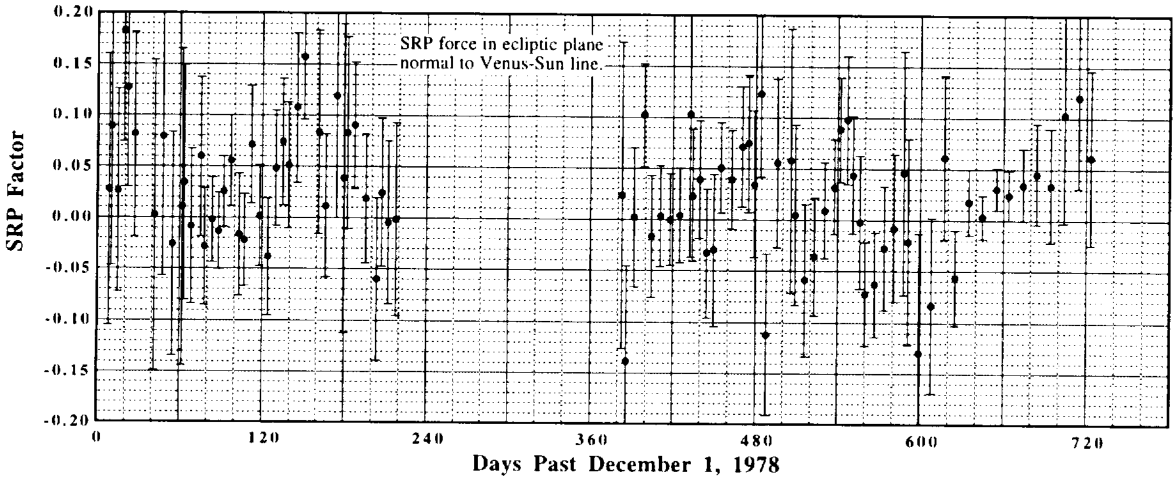


Figure 44: PVO Low-Orbit Solar Radiation Pressure (GY) Solution

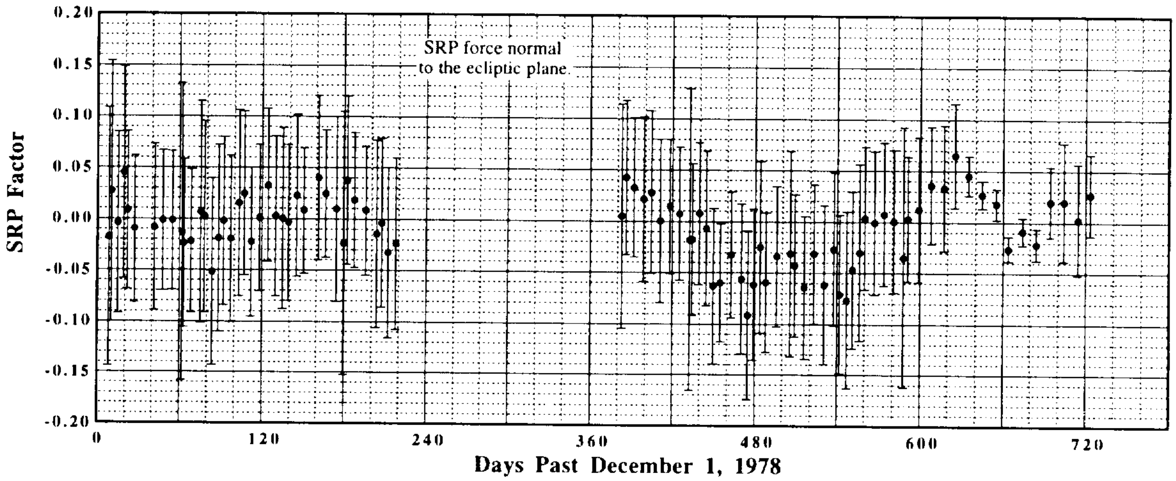


Figure 45: PVO High-Orbit Solar Radiation Pressure (GR) Solution

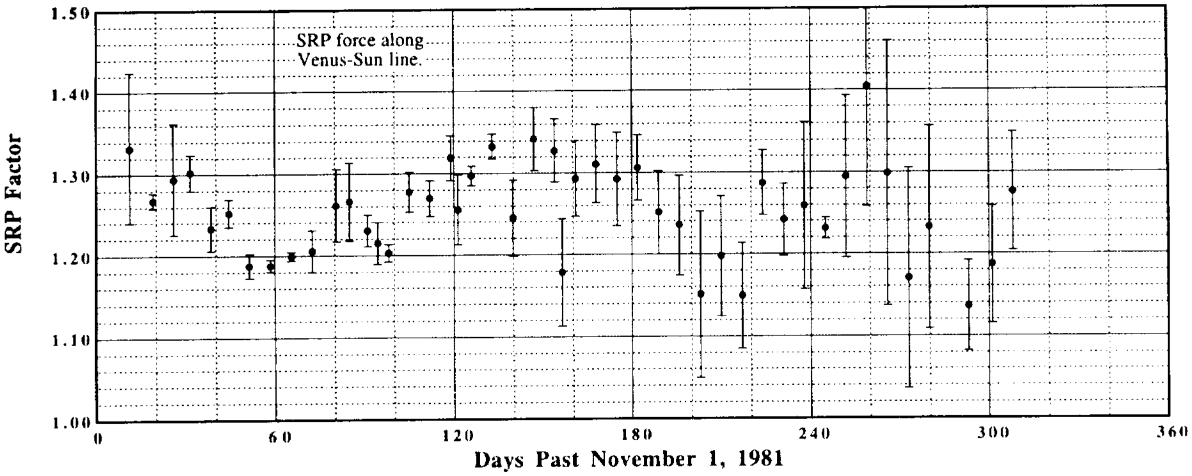


Figure 46: PVO High-Orbit Solar Radiation Pressure (GX) Solution

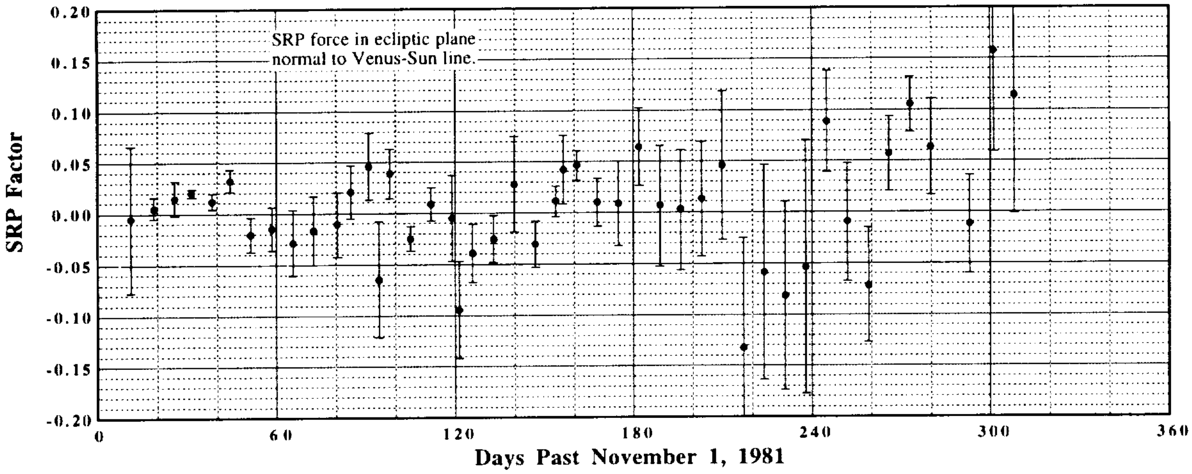
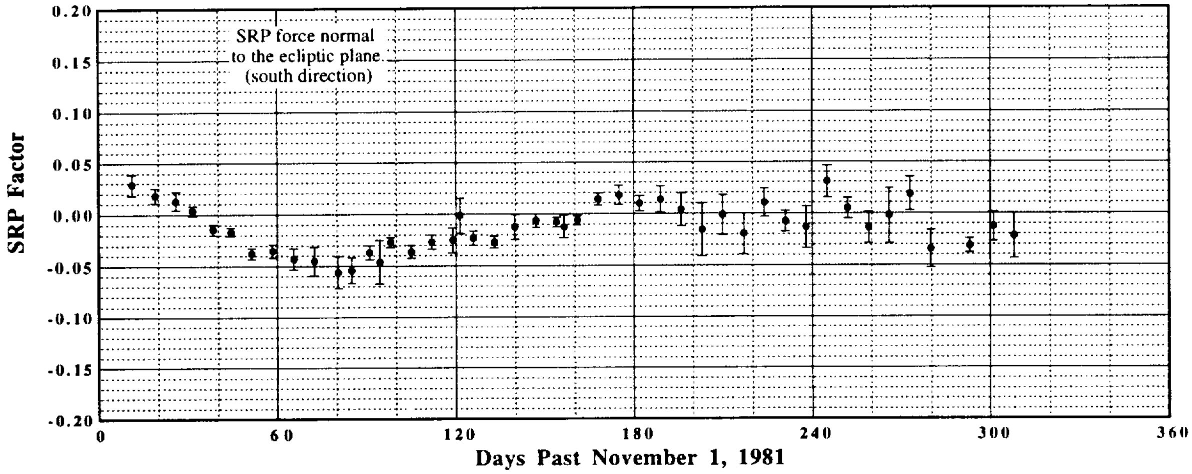


Figure 47: PVO High-Orbit Solar Radiation Pressure (GY) Solution



substantially relaxed then the values remain negative but fluctuate between -0.2 and -0.01. Also, they do not constrain the accommodation coefficient better than ±0.2. The $C_{l/d}$ is only determined on the dayside where the density at the spacecraft is large. Future studies may investigate a sideslip (out of orbit plane) force that may be due to a moving atmosphere or a spacecraft orientation in the atmosphere.

The Magellan densities are not as well determined as those for PVO due to the higher altitude and shorter orbit period. The densities are constrained to 1.0x10-12 gm/cm^3 with 100% uncertainty. The resulting density solutions have uncertainties of about 1x10-12 gm/cm^3 with higher density values on the dayside and lower density values on the nightside. There is not nearly the density information for Magellan as there is for PVO. Future gravity models will constrain the density solutions closer to the VIRA values. The Magellan spacecraft passes through the atmosphere with the solar array axis along the velocity vector and so the drag is mainly from the spacecraft bus and high gain antenna. The antenna is at a right angle to the direction of flow. With the solar panels titled by 10 degrees into the direction of flow (80 degree angle of attack) the cross sectional area of the spacecraft is about 10 m^2.

7b. Solar Pressure

The solar pressure solutions for the low-altitude and high-altitude PVO data are shown in Figures 42, 43, 44, 45, 46, and 47 for the three orthogonal solar pressure coefficients. The low-altitude uncertainties for the solar pressure are greater than the high-altitude due to the loss of information from the drag. The high-altitude solar pressure shows some systematic trends which are probably related to the modeling of solar pressure on the antenna as the antenna remains pointed to the Earth or to the albedo force from Venus. The albedo solution for the high-altitude PVO orbits (not shown) shows a systematic trend like the solar pressure and seems to be a function of the LST. It is probably related to varying reflectance properties of the Venusian clouds versus the incidence angles since the variations of 10% are greater than observed variations in the Venus albedo (which may be 1% at most). The albedo model assumes isotropic and diffuse reflectance from the Venus clouds. Taylor and Stowe (1984) have shown that for the Earth the reflectance is more specular for high incidence angles and the flux can vary by 10% to 20% depending on the zenith angle of the Sun and spacecraft and the relative azimuth. These systematic trends will be investigated in more detail in future analysis. The solar coefficients have an a priori uncertainty of 0.2 and are fairly well determined. The solar pressure solutions for the Magellan arcs are very poorly determined (the a priori uncertainty is not reduced) because of the increased number of atmospheric drag passages and the shorter data arcs.

Future efforts will attempt to improve the solar pressure model (maybe orientation, reflectivity coefficients) and increase the arc lengths - especially the high-altitude PVO orbits. With a better model and increased arcs, this should improve the information in the low degree harmonics and other global parameters such as the Love number.

8. Summary

With the gravity software now running on the massively parallel JPL Cray T3D Supercomputer, we have been able to increase the resolution of the Venus gravity field with dramatic improvements in the amount of time required to generate the solution (on the order of weeks for the supercomputer versus years with workstations). The Venus gravity model MGNP90LSAAP which is complete to degree and order 90 represents the best gravity solution to date. It shows increased correlation with topography over the last solution MGNP75ISAAP with minor improvements in the lower to medium degree harmonics and more improvement in the higher degree. Interpretation for smaller features (e.g., Mead Crater and Maat Mons) shows substantial improvement. The topography and this gravity model, which has been provided to the science community, provide the basis of geophysical interpretation.

Other parameters were estimated along with the gravity field. For the first time, we are sensing a Love number for another planet, perhaps indicating a liquid core. The Venus spin pole solution is most likely the best solution and the rotation rate of Venus is determined to a comparable level of the Magellan SAR data. The GM estimate for Venus is the best estimate to date and slightly better than previous determinations.

The models affecting the gravity solution have been reviewed. Many parameters and geometries that are useful in evaluating the Doppler data have been provided in the Appendices, hopefully making this a useful handbook.

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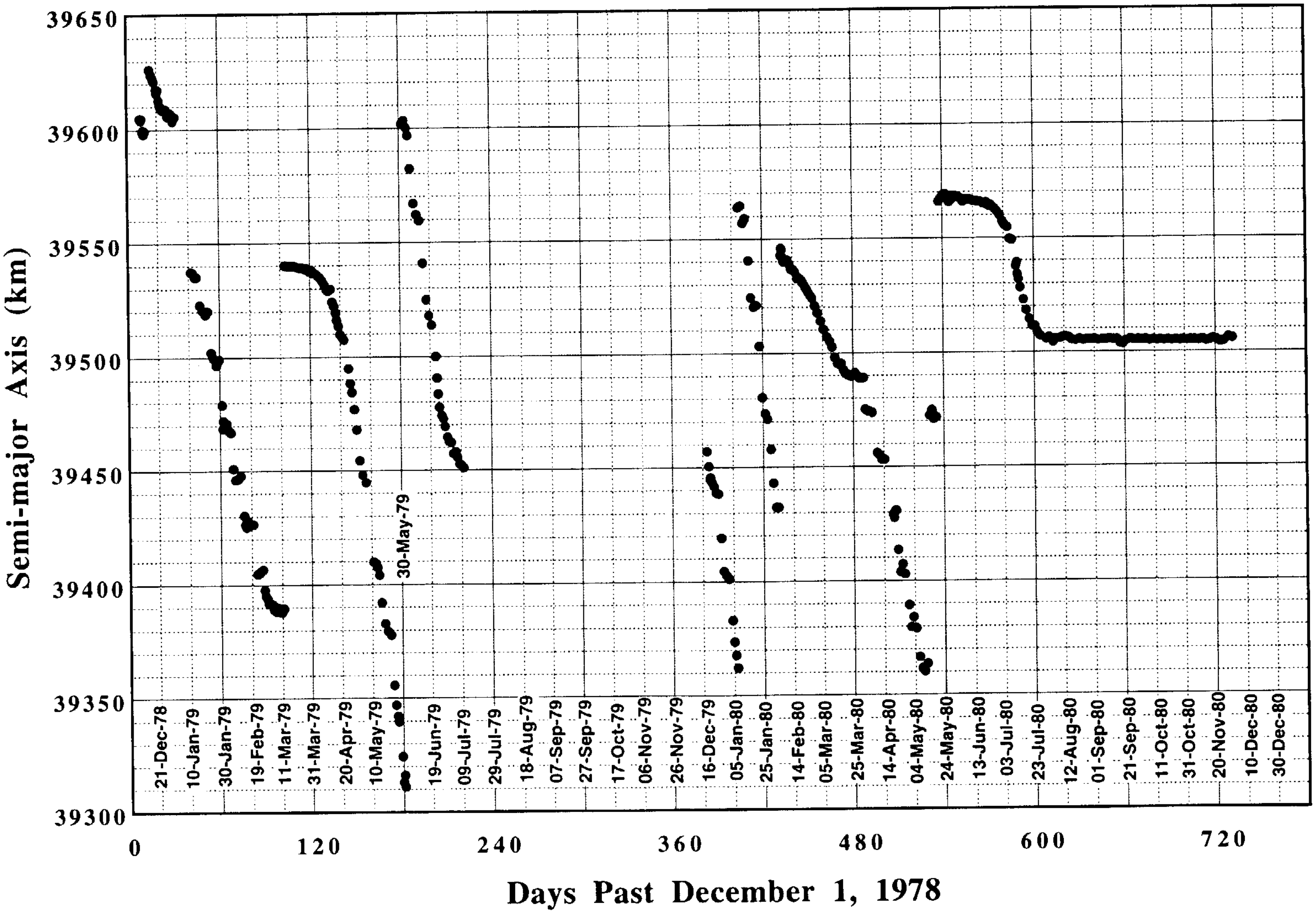
Appendix A

PVO Low-Altitude Periapse Information

The following plots are included in this appendix:

1. Semi-major axis
2. Eccentricity
3. Inclination
4. Latitude at periapse
5. Longitude at periapse
6. Altitude at periapse
7. Plane-of-sky inclination
8. One-way light time from Venus to Earth
9. Sun-Earth-Venus angle
10. Earth-Venus-Probe at periapse angle
11. Local solar time at periapse
12. Altitude vs. latitude profile

PVO Low Orbit Semi-Major Axis



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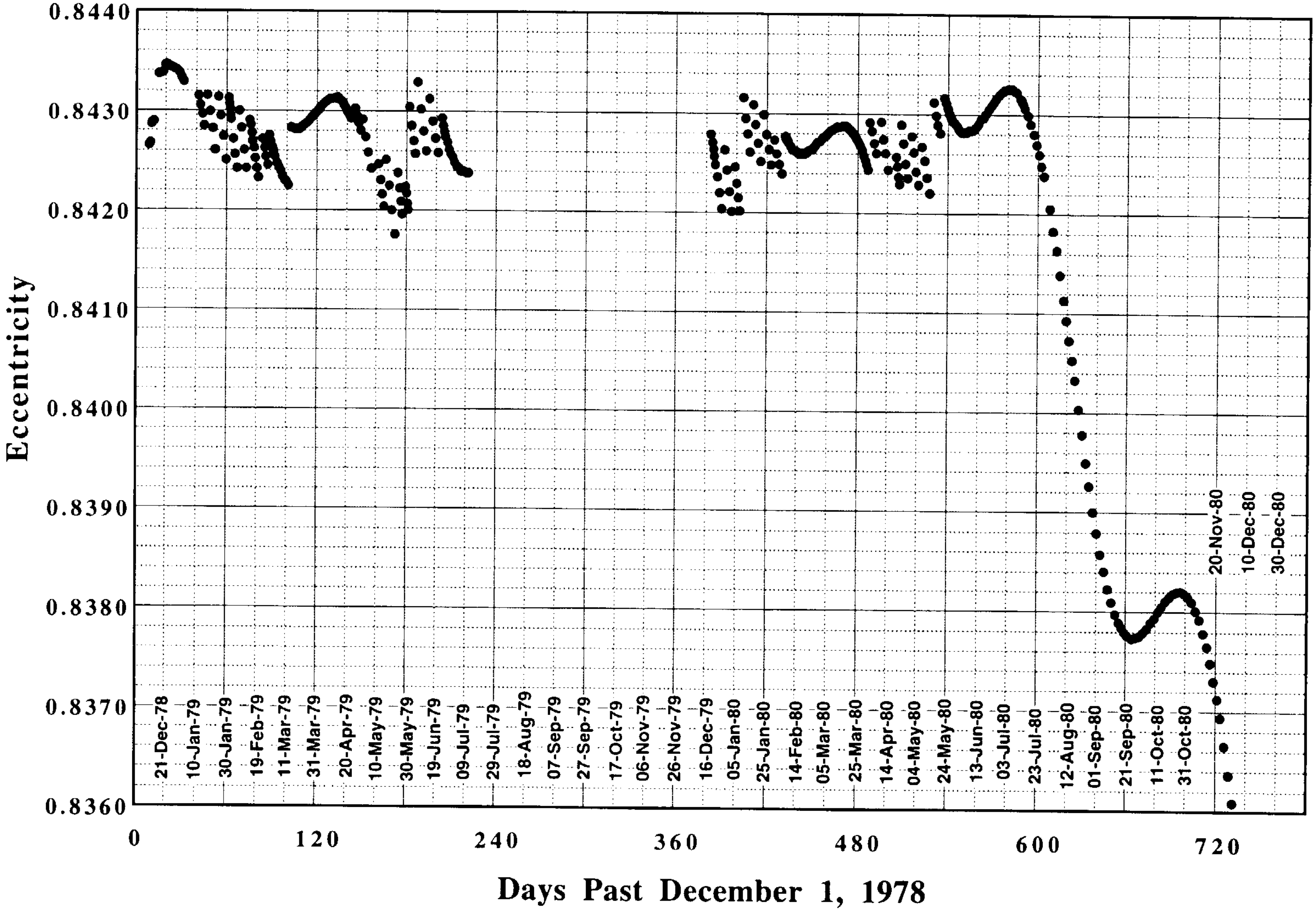

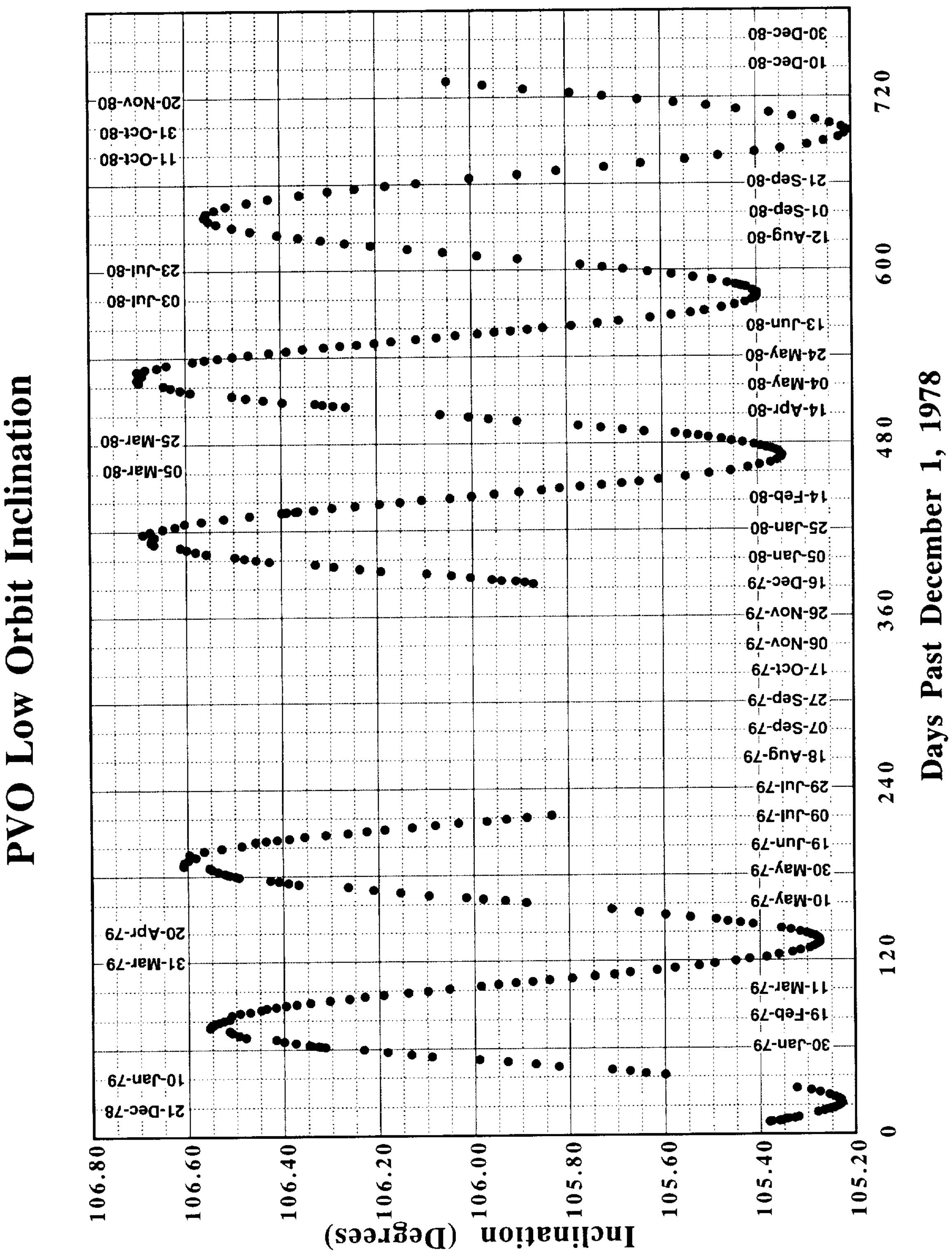
PVO Low Orbit Inclination
Inclination (Degrees)
106.80
106.60
106.40
106.20
106.00
105.80
105.60
105.40
105.20
Days Past December 1, 1978
0
120
240
360
480
600
720
21-Dec-78
10-Jan-79
30-Jan-79
19-Feb-79
11-Mar-79
31-Mar-79
20-Apr-79
10-May-79
30-May-79
19-Jun-79
09-Jul-79
29-Jul-79
18-Aug-79
07-Sep-79
27-Sep-79
17-Oct-79
06-Nov-79
26-Nov-79
16-Dec-79
05-Jan-80
25-Jan-80
14-Feb-80
05-Mar-80
25-Mar-80
14-Apr-80
04-May-80
24-May-80
13-Jun-80
03-Jul-80
23-Jul-80
12-Aug-80
01-Sep-80
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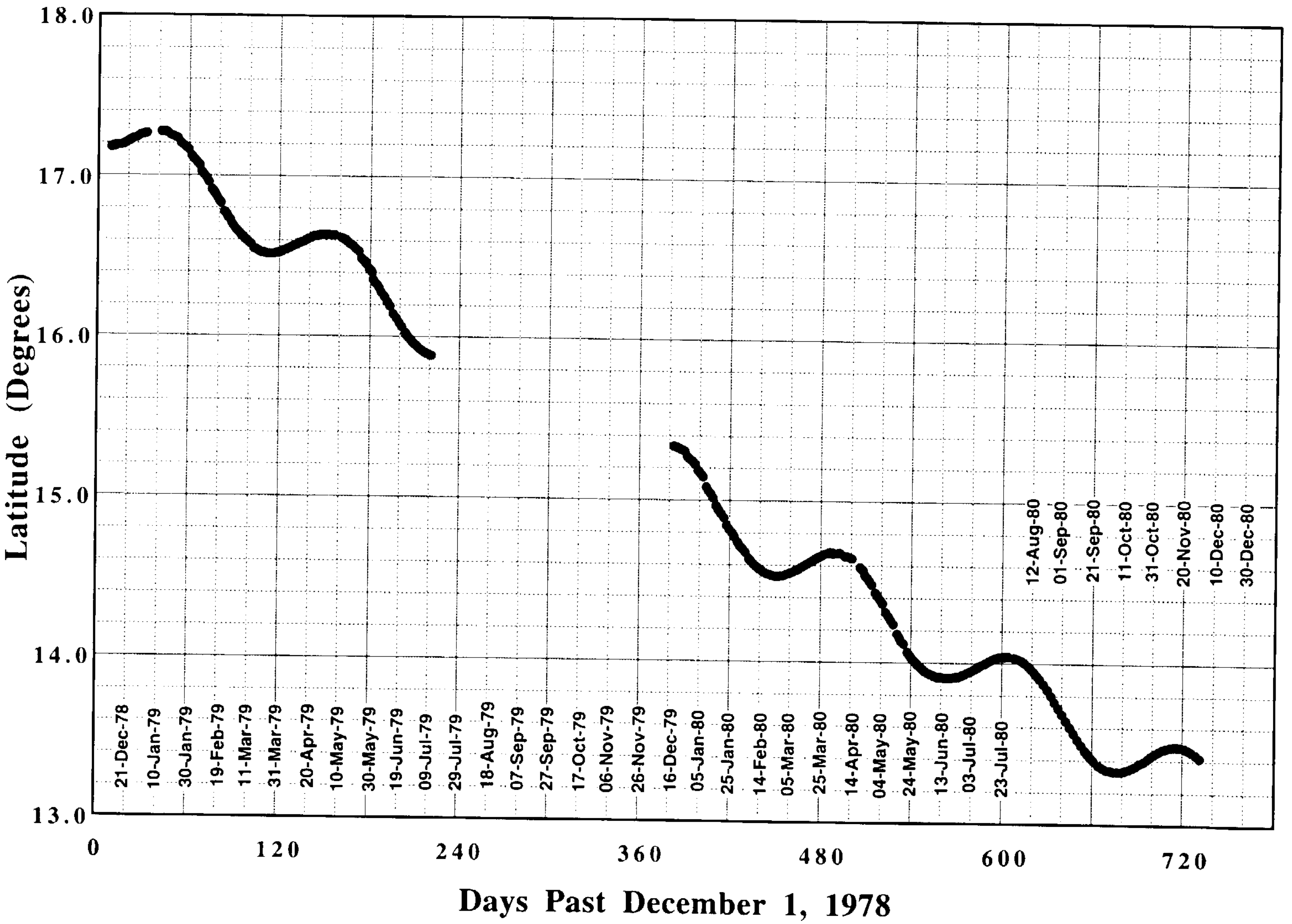
20-Nov-80
10-Dec-80
30-Dec-80

PVO Low Orbit Latitude at Periapse



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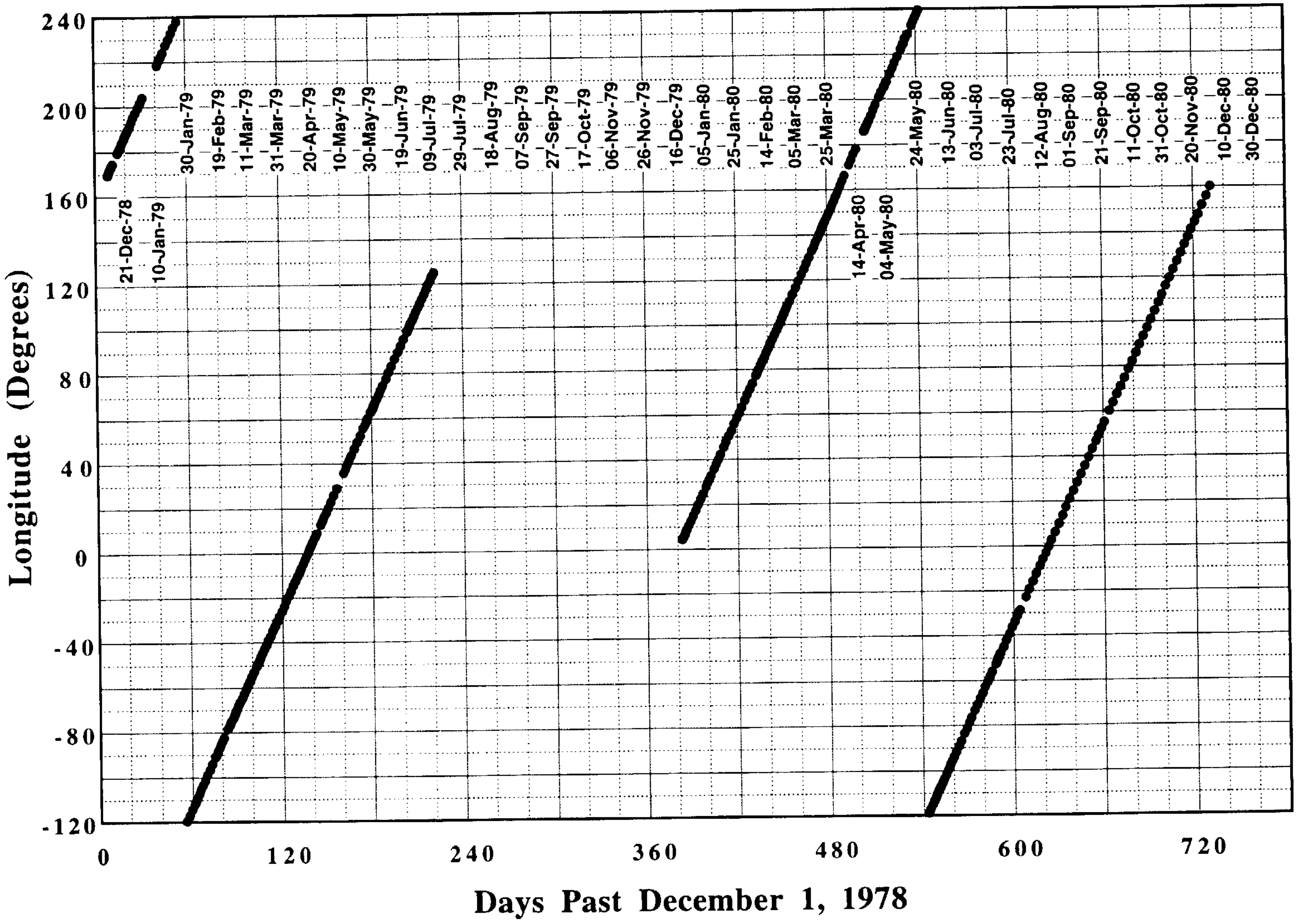

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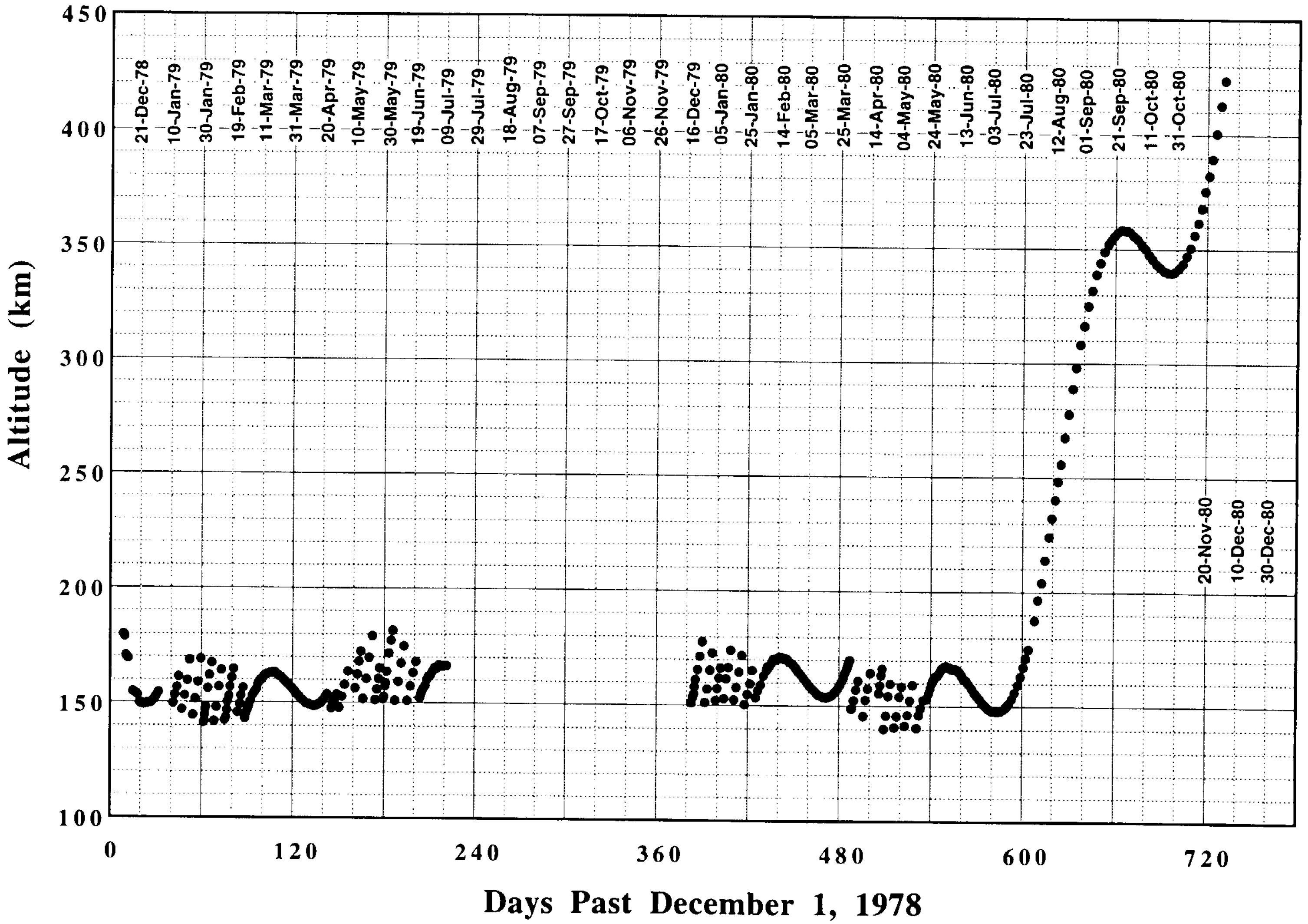
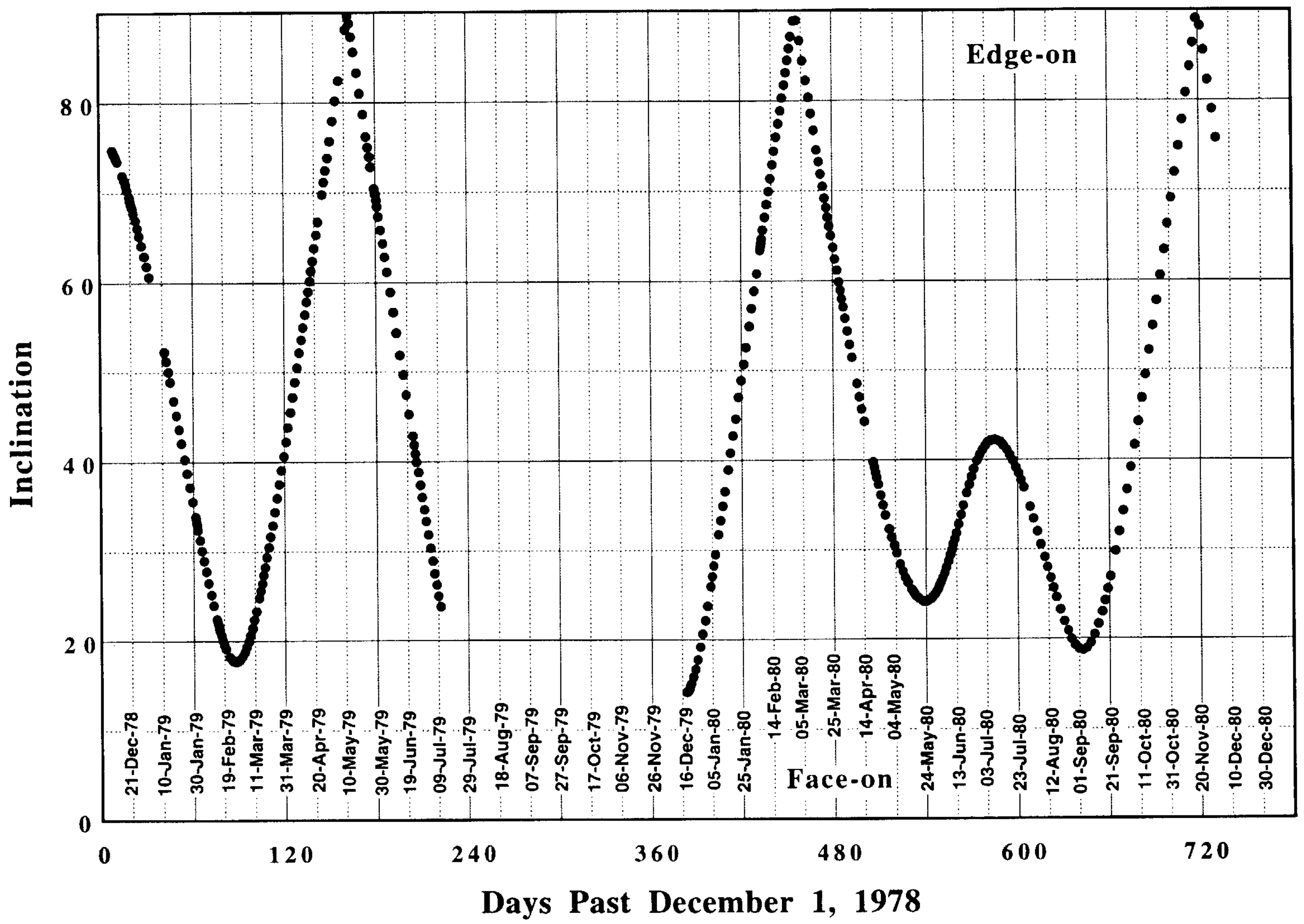
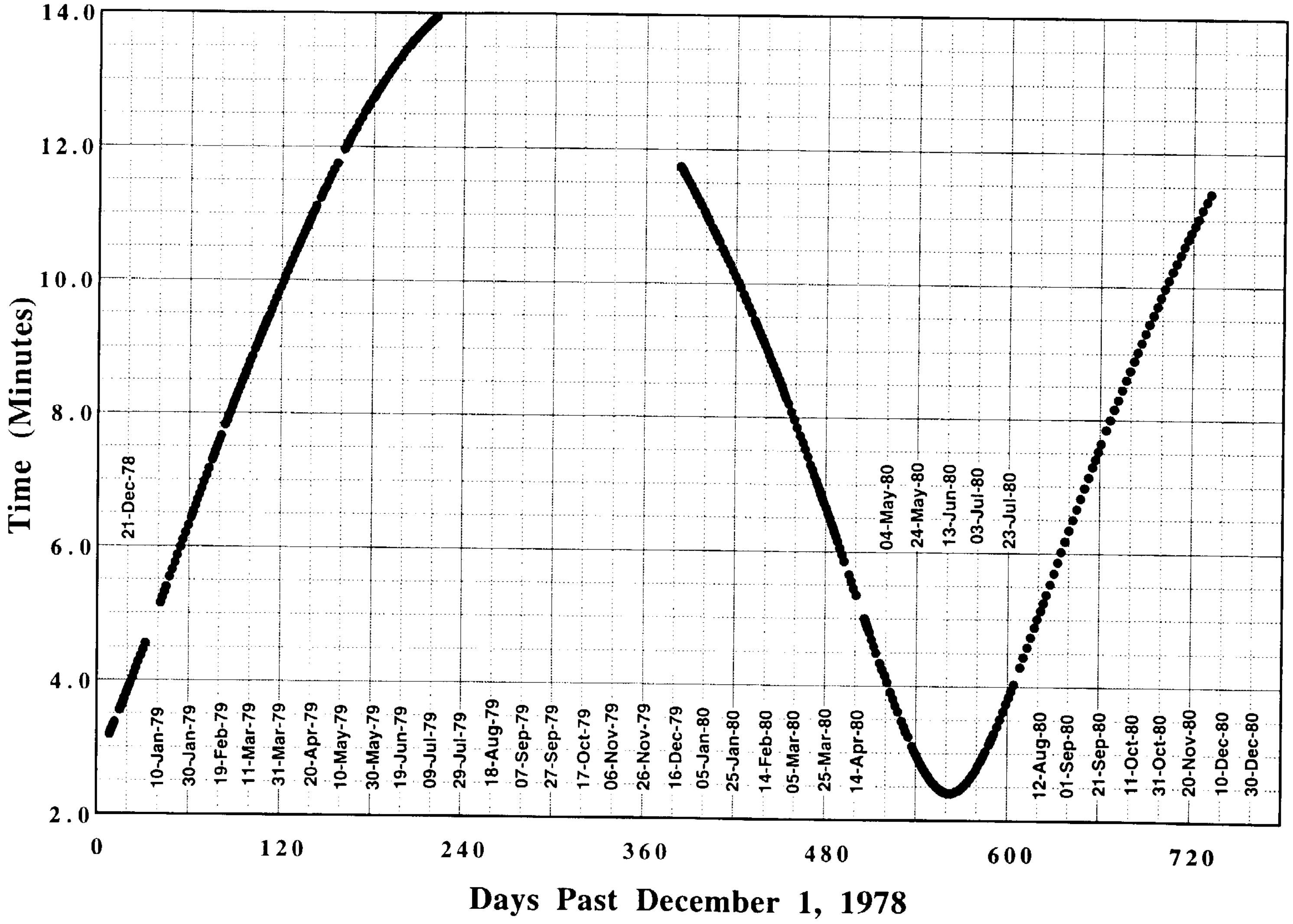


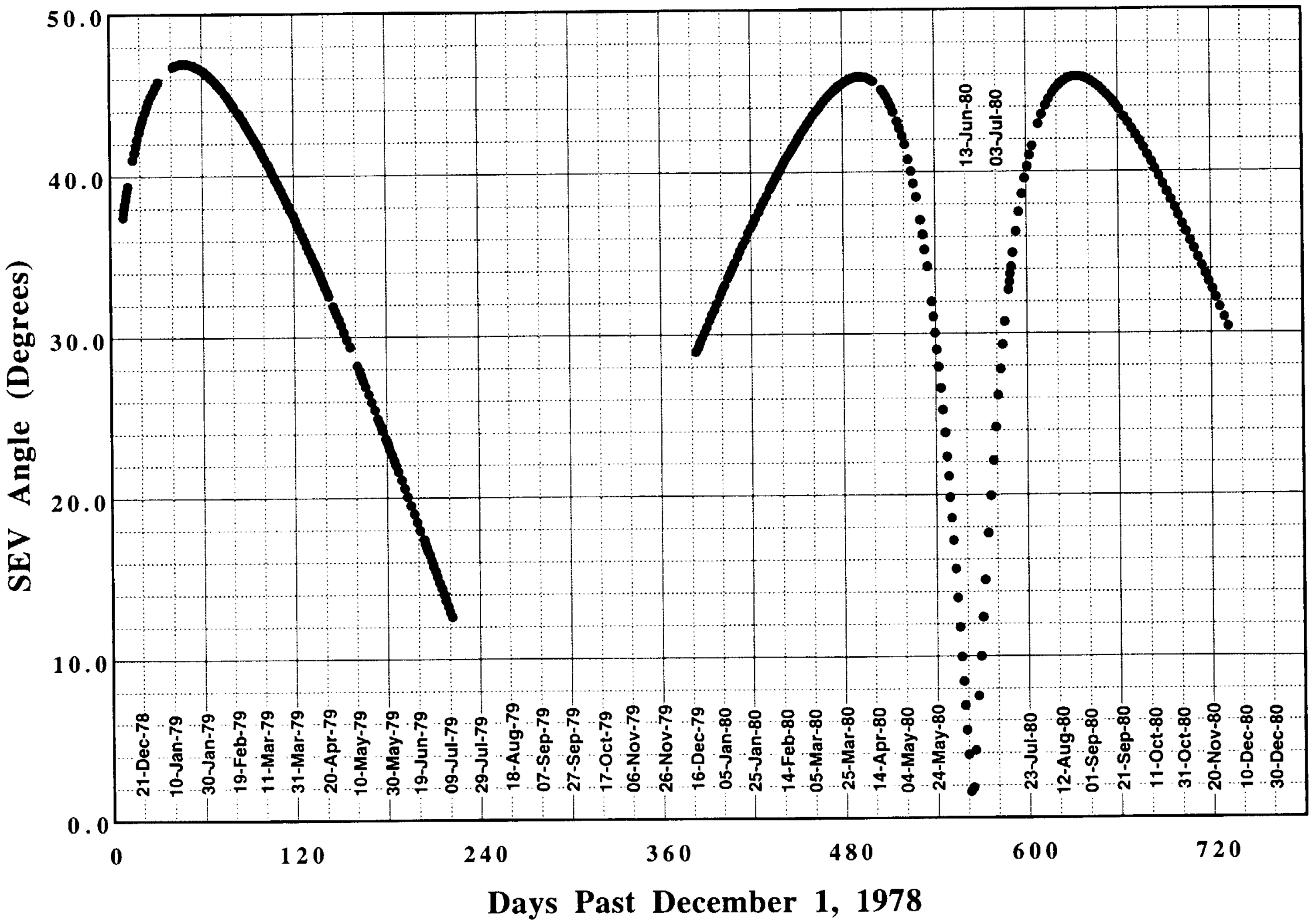
PVO Low Orbit Plane-of-Sky Inclination



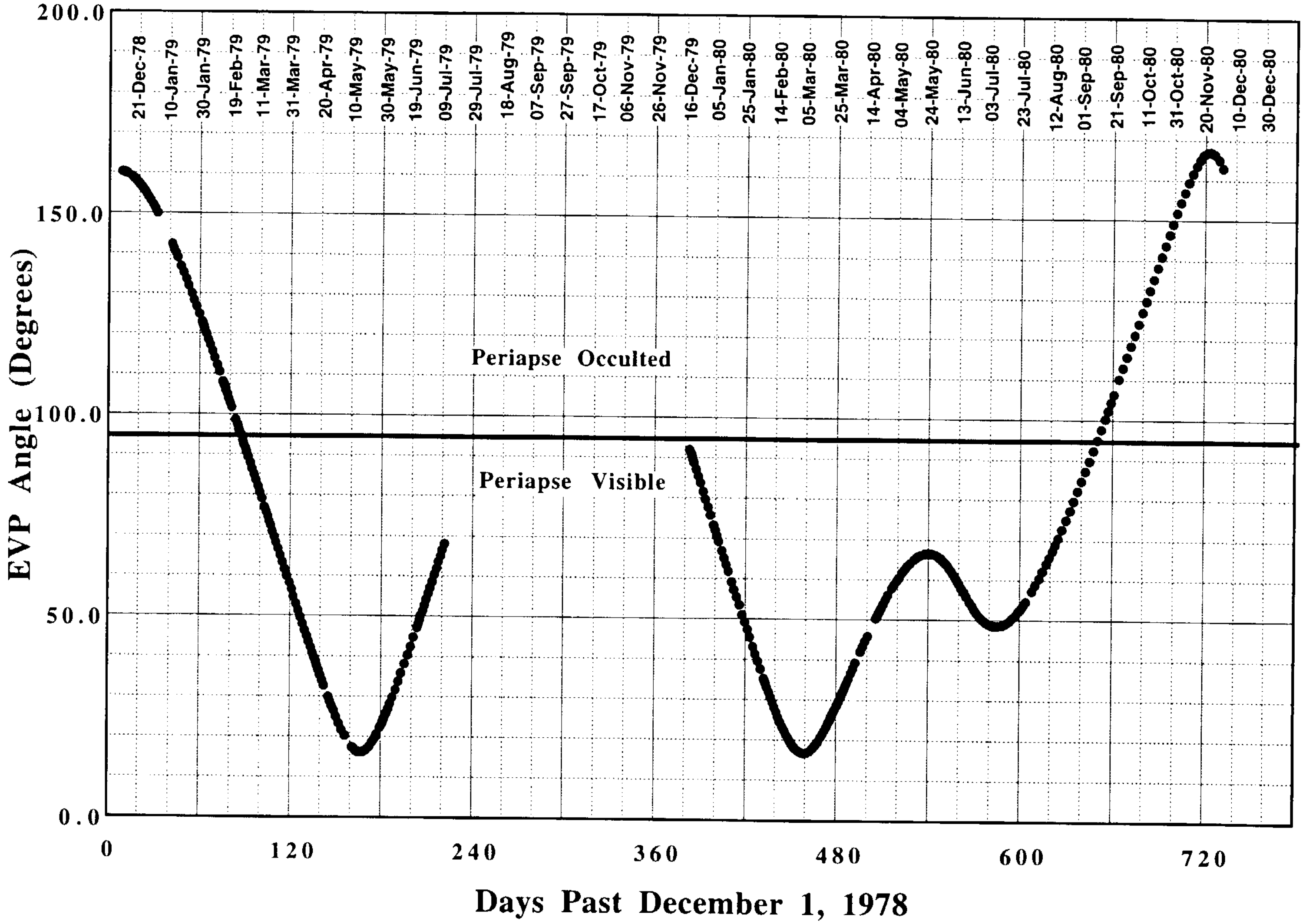
PVO Low Orbit One-Way-Light-Time



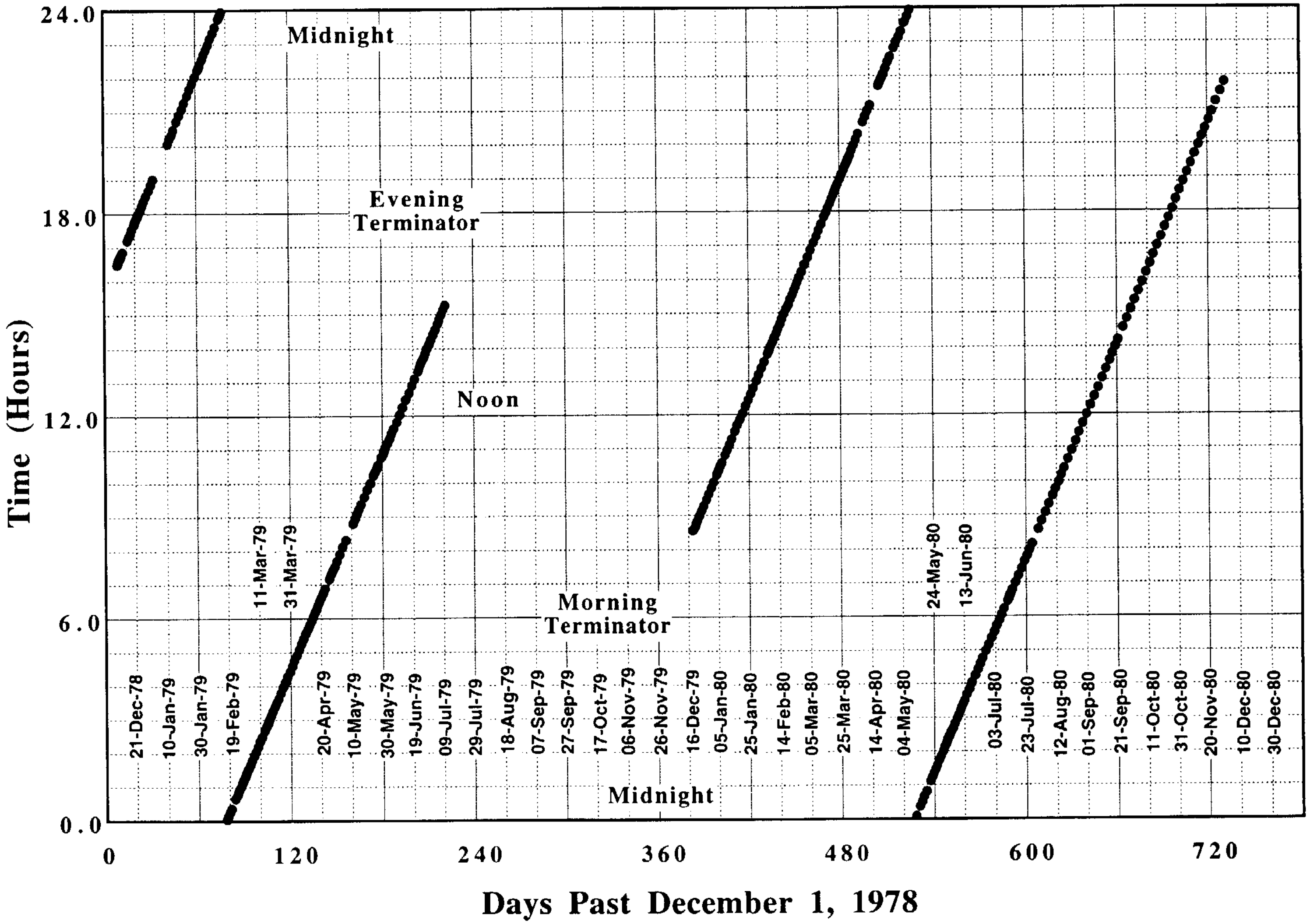
PVO Low Orbit Sun-Earth-Venus Angle



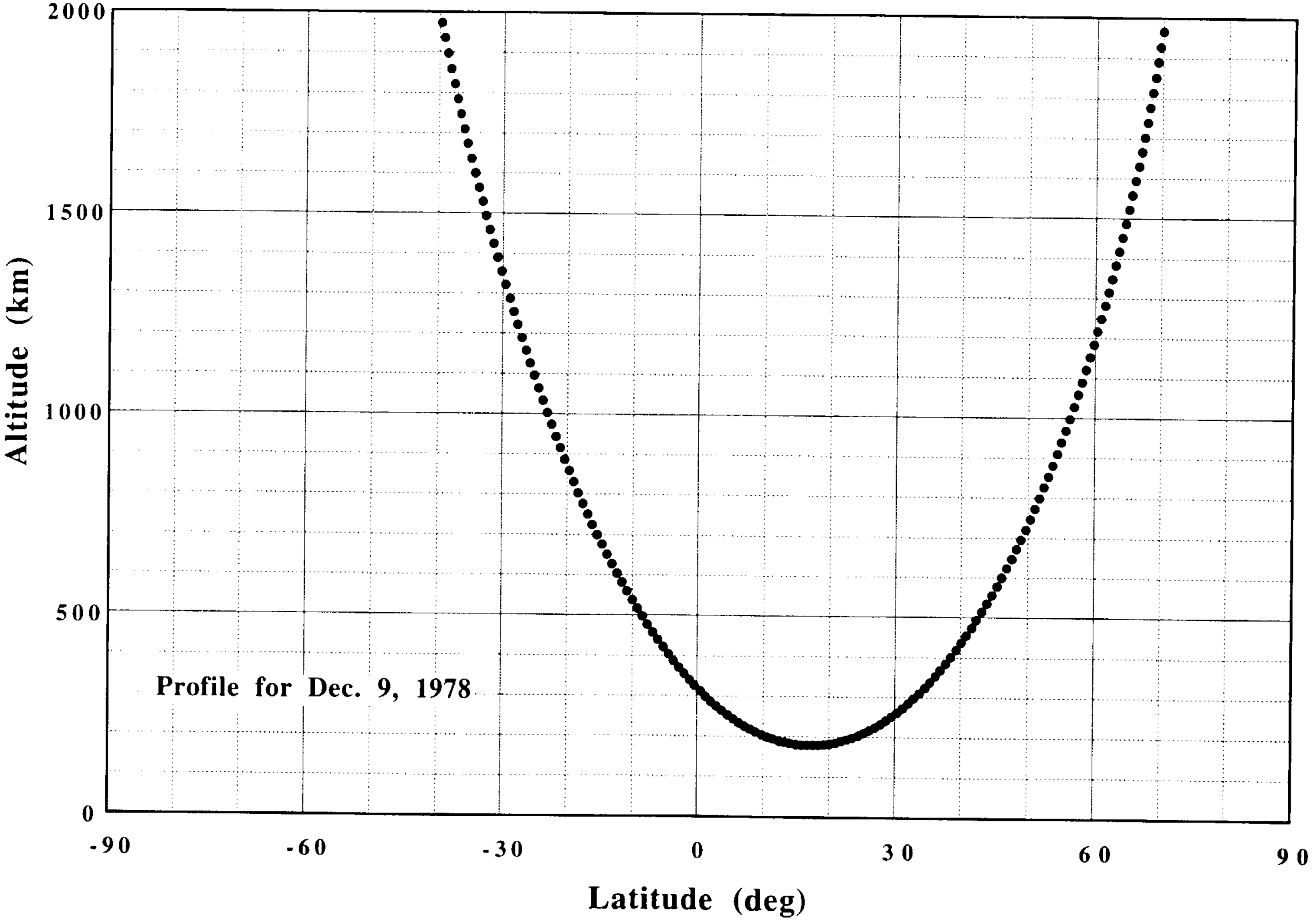
PVO Low Orbit Earth-Venus-Probe at Periapse Angle



PVO Low Orbit Local Solar Time at Periapse



PVO Low Orbit Altitude vs Latitude



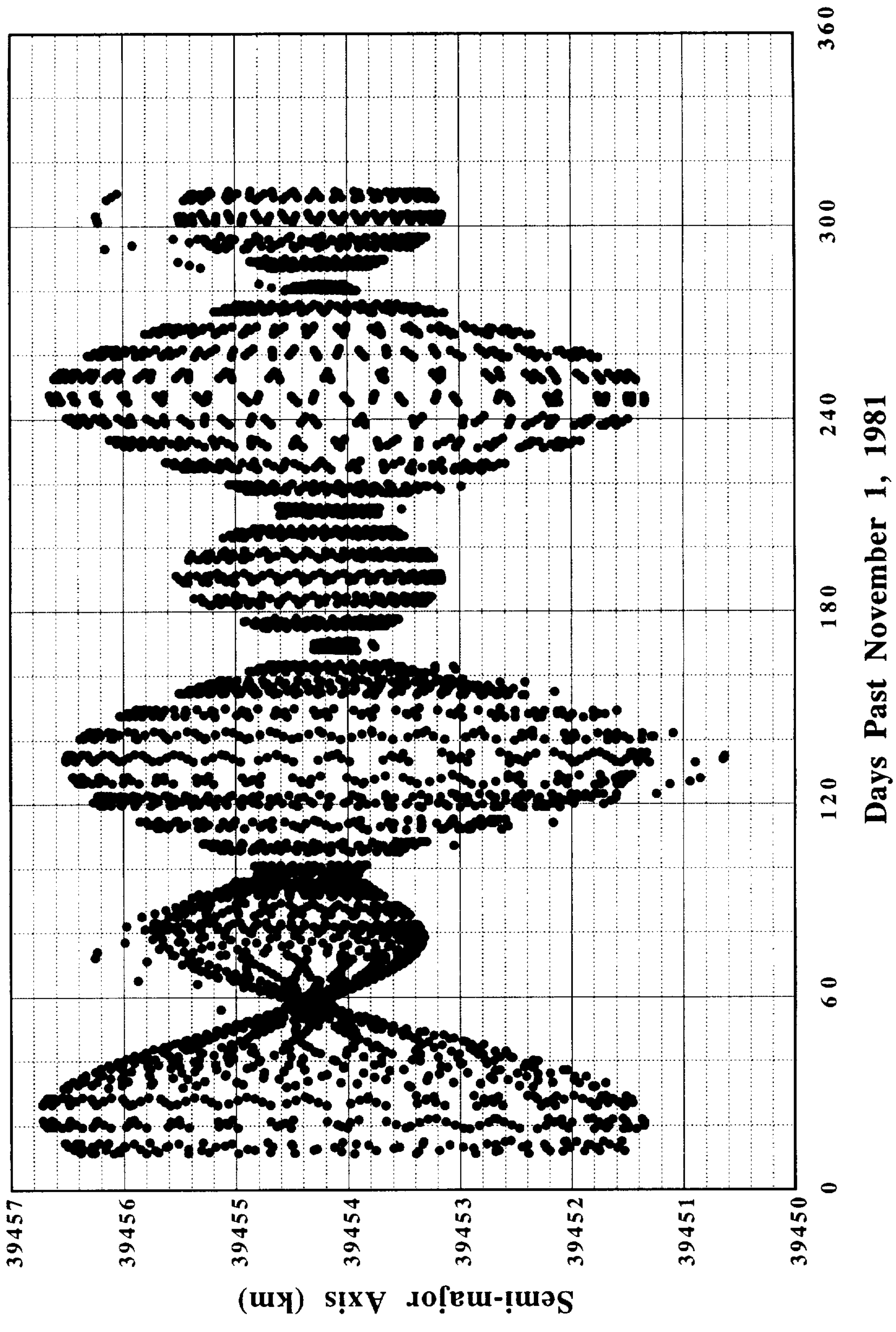
Appendix B

PVO High-Altitude Periapse Information

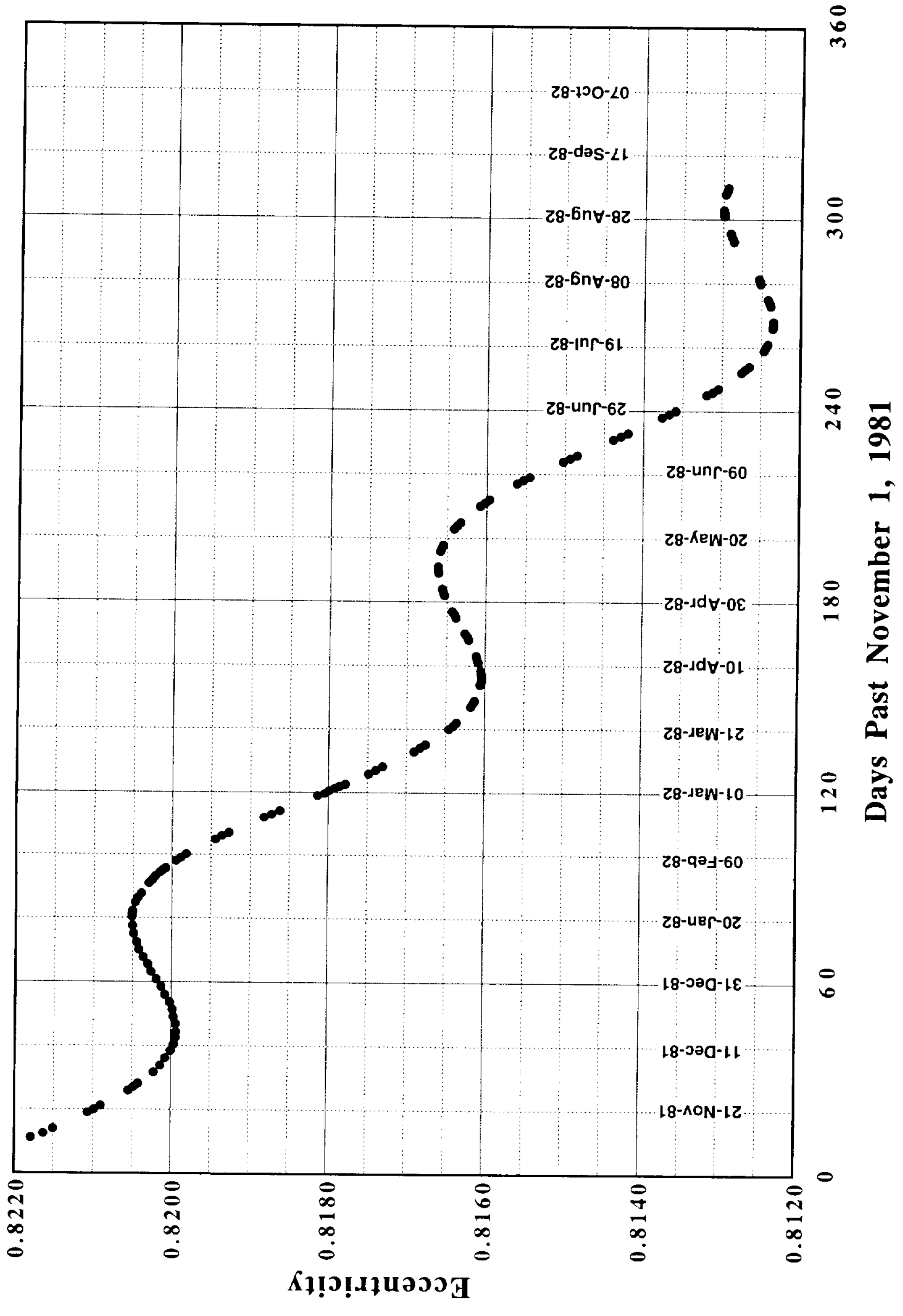
The following plots are included in this appendix:

1. Semi-major axis
2. Eccentricity
3. Inclination
4. Latitude at periapse
5. Longitude at periapse
6. Altitude at periapse
7. Plane-of-sky inclination
8. One-way light time from Venus to Earth
9. Sun-Earth-Venus angle
10. Earth-Venus-Sun angle
11. Earth-Venus-Probe at periapse angle
12. Local solar time at periapse

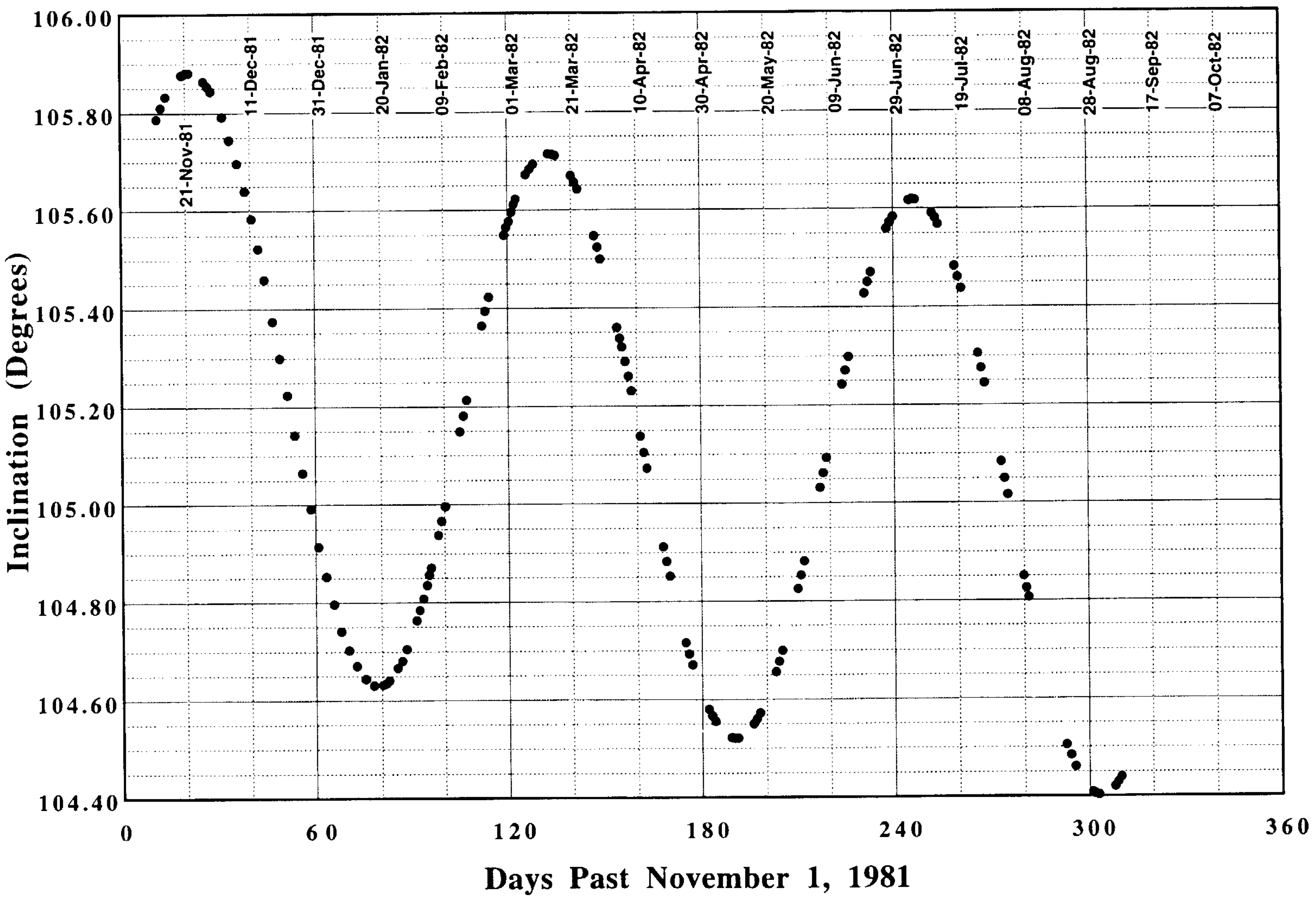
PVO High Orbit Semi-Major Axis



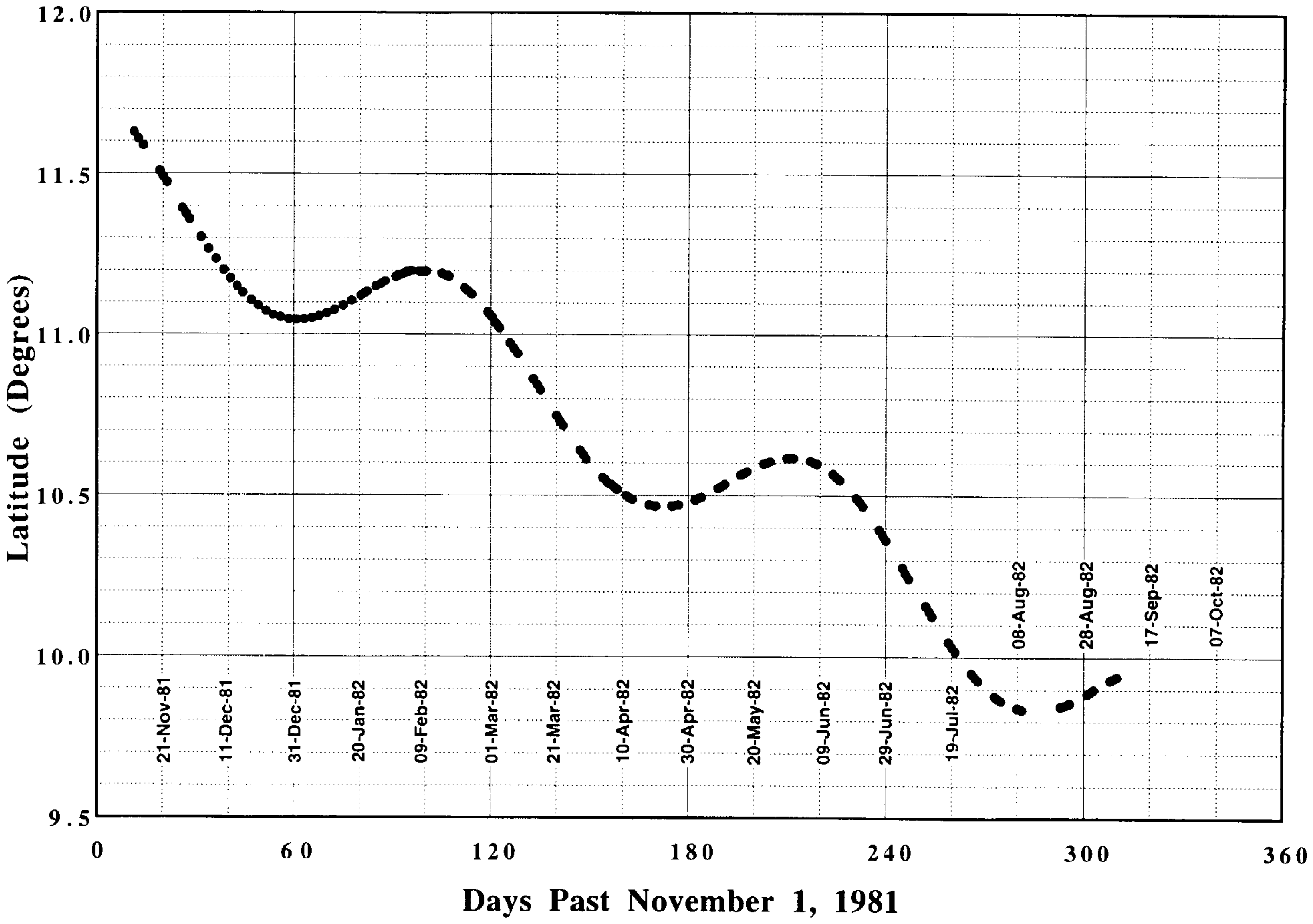
PVO High Orbit Eccentricity



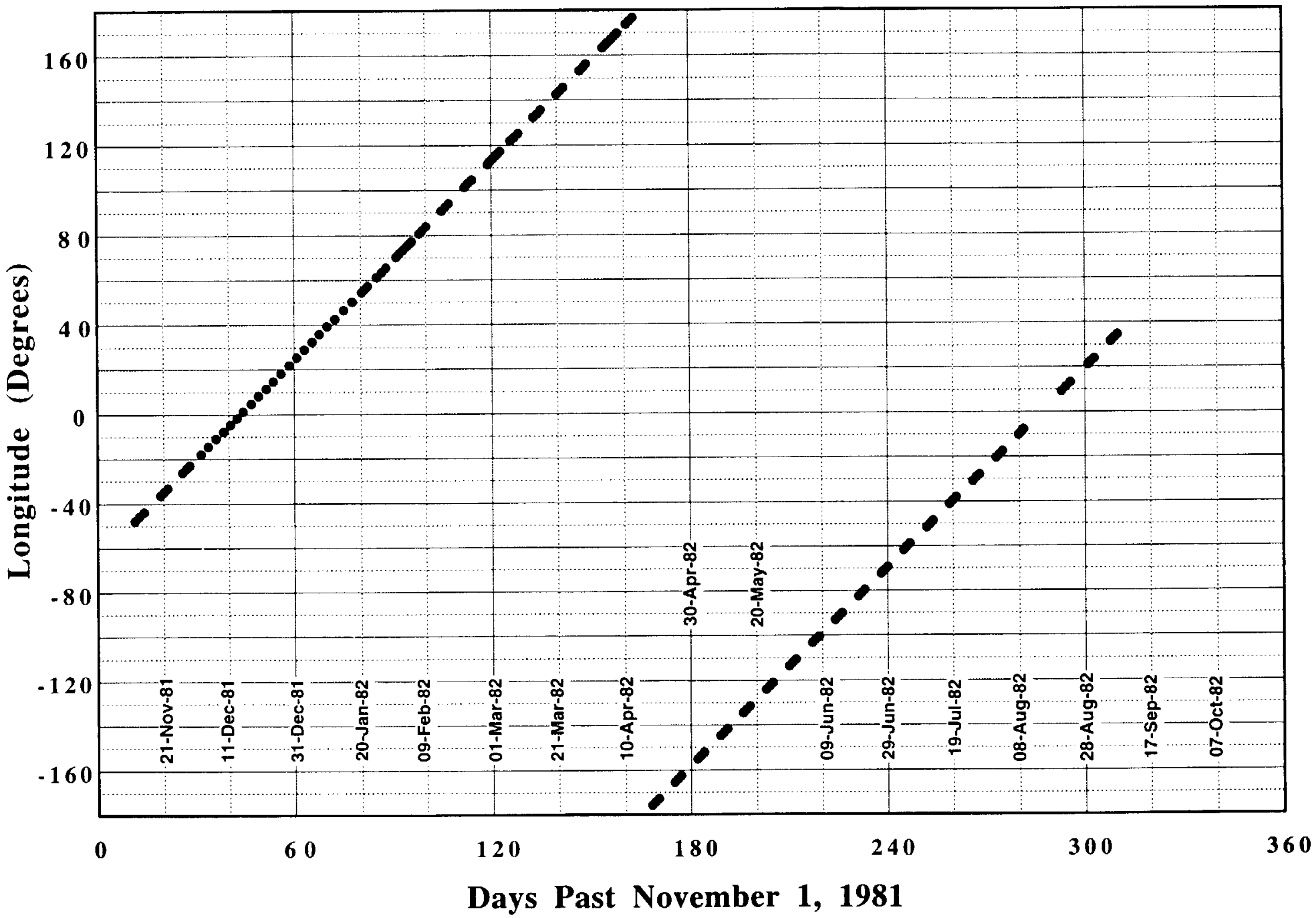
PVO High Orbit Inclination



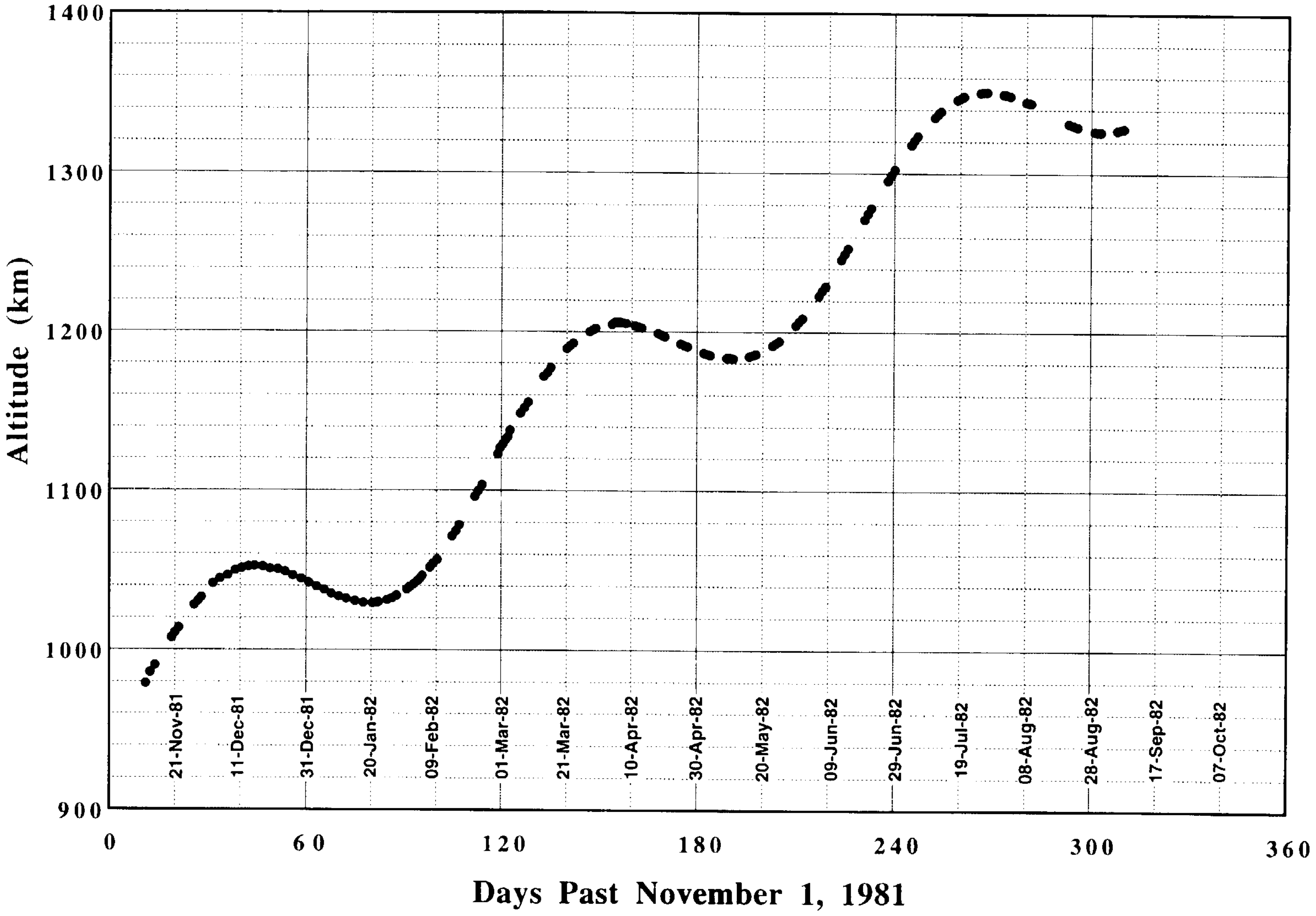
PVO High Orbit Latitude at Periapse



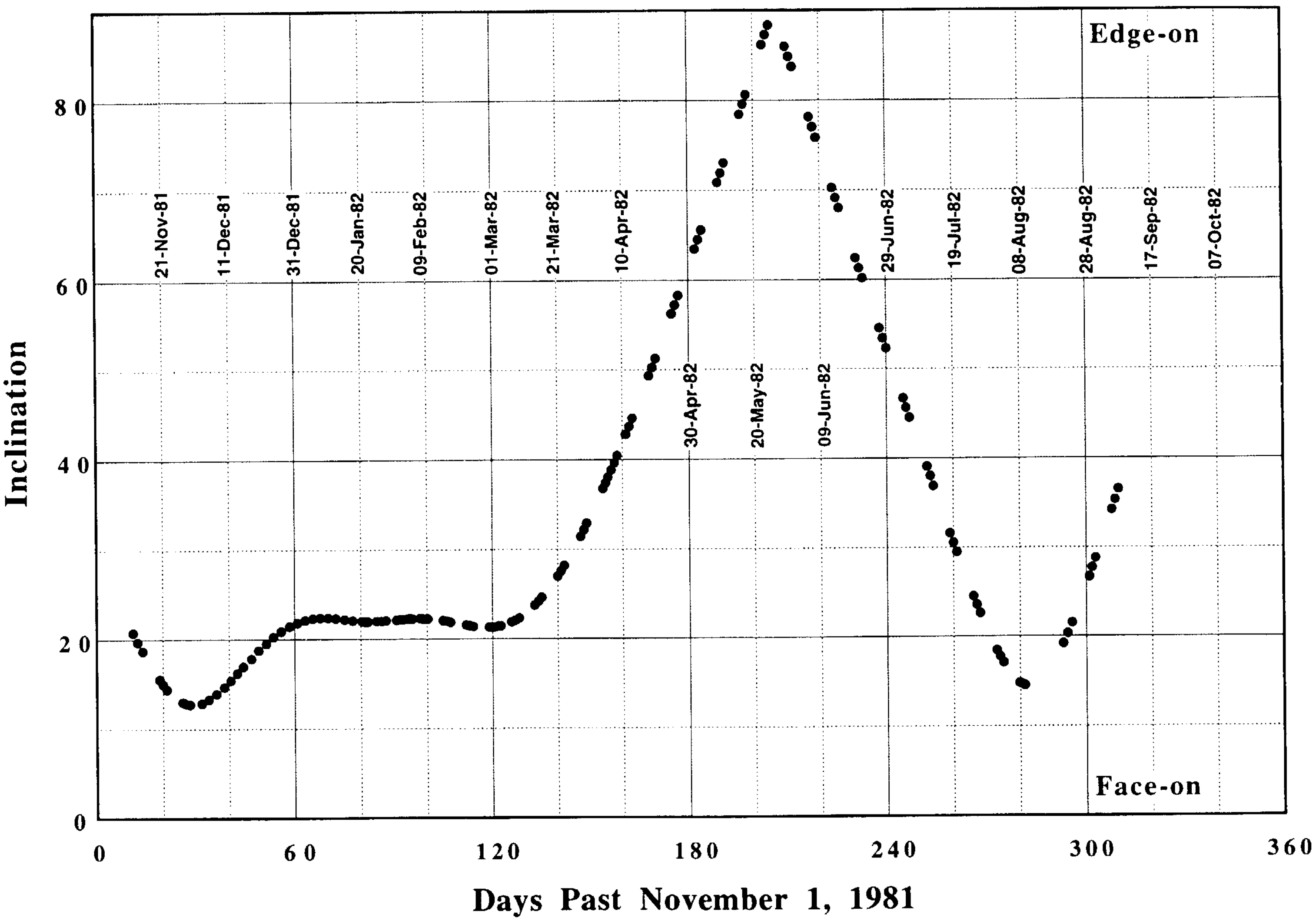
PVO High Orbit Longitude at Periapse



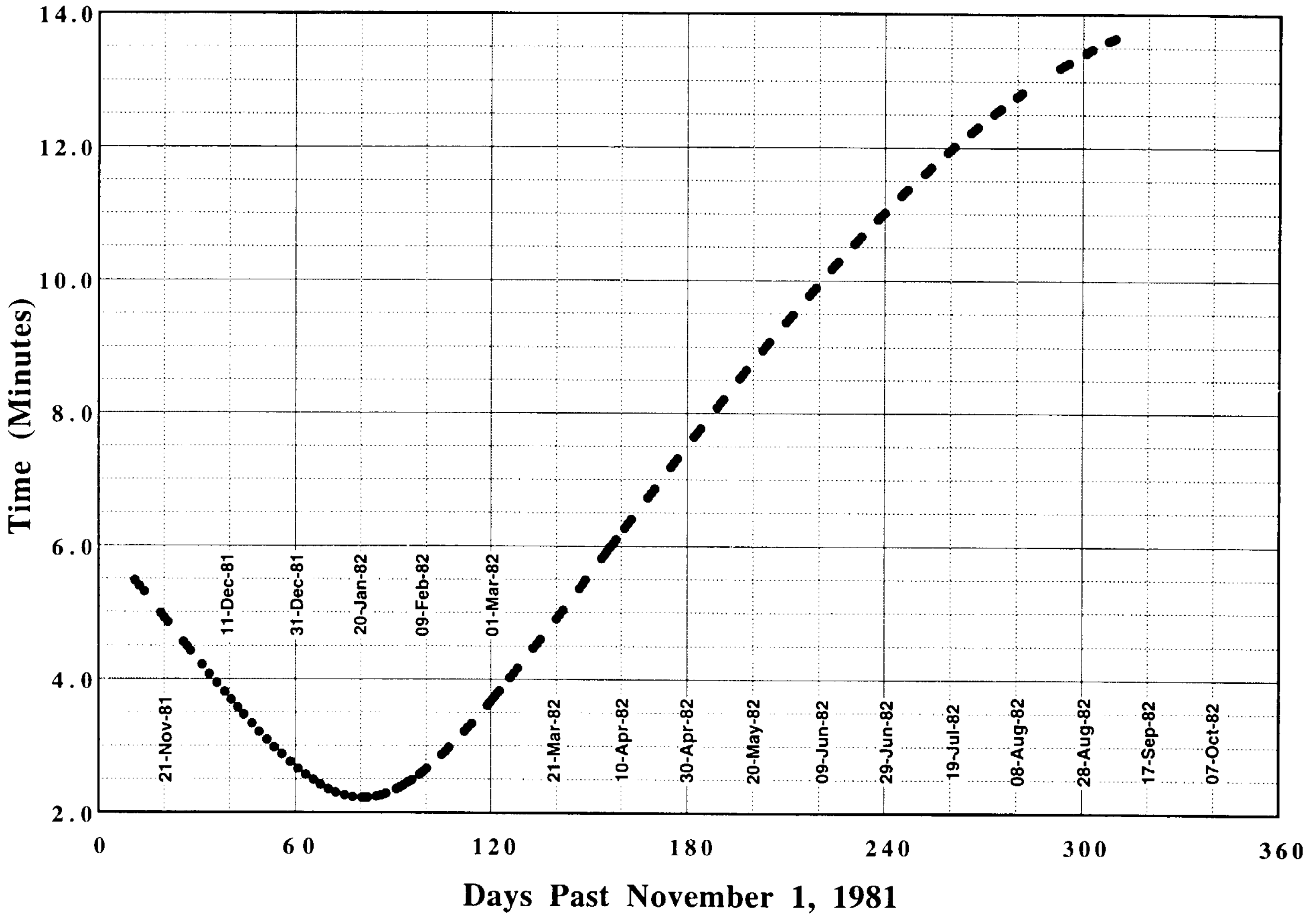
PVO High Orbit Altitude at Periapse



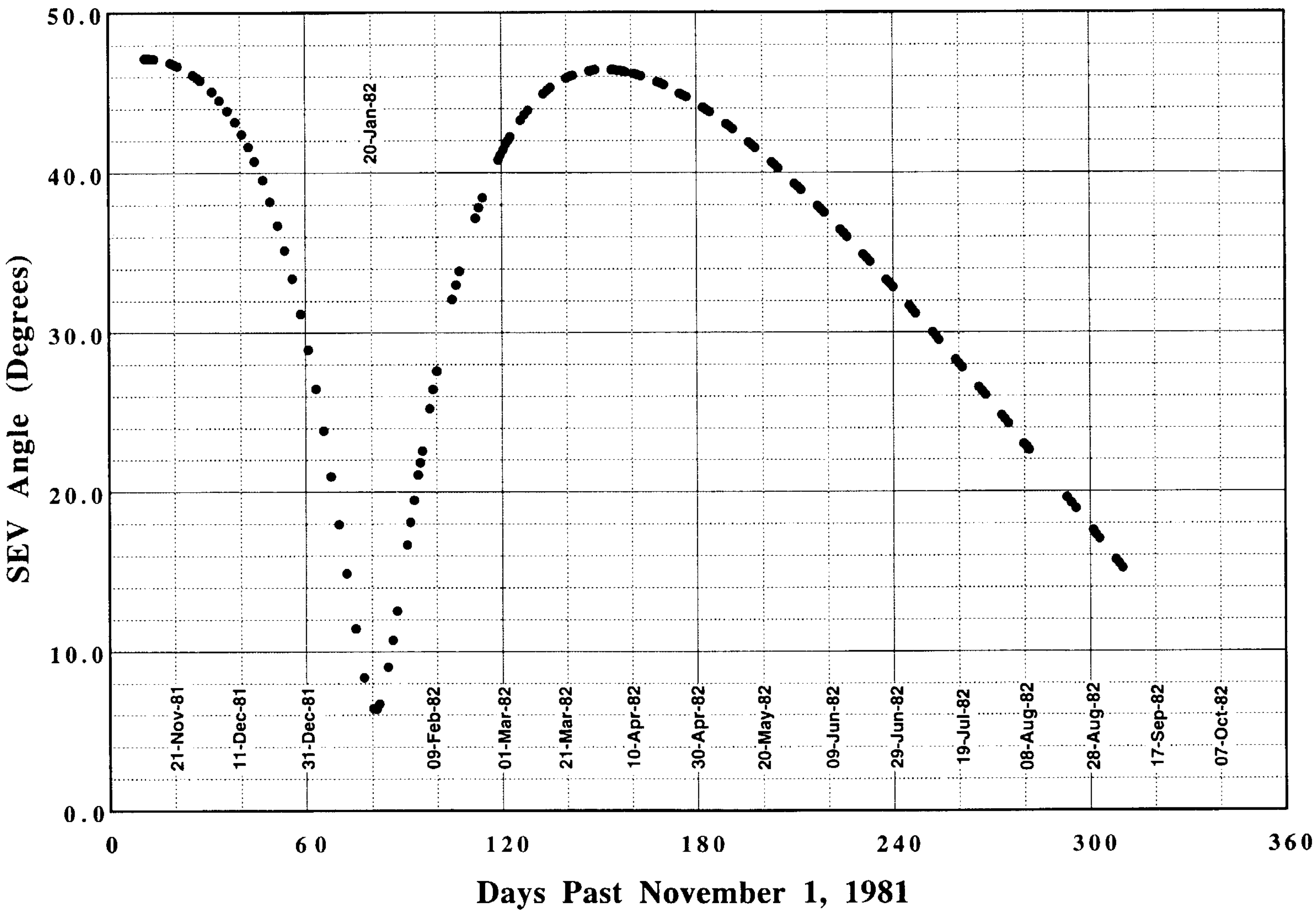
PVO High Orbit Plane-of-Sky Inclination



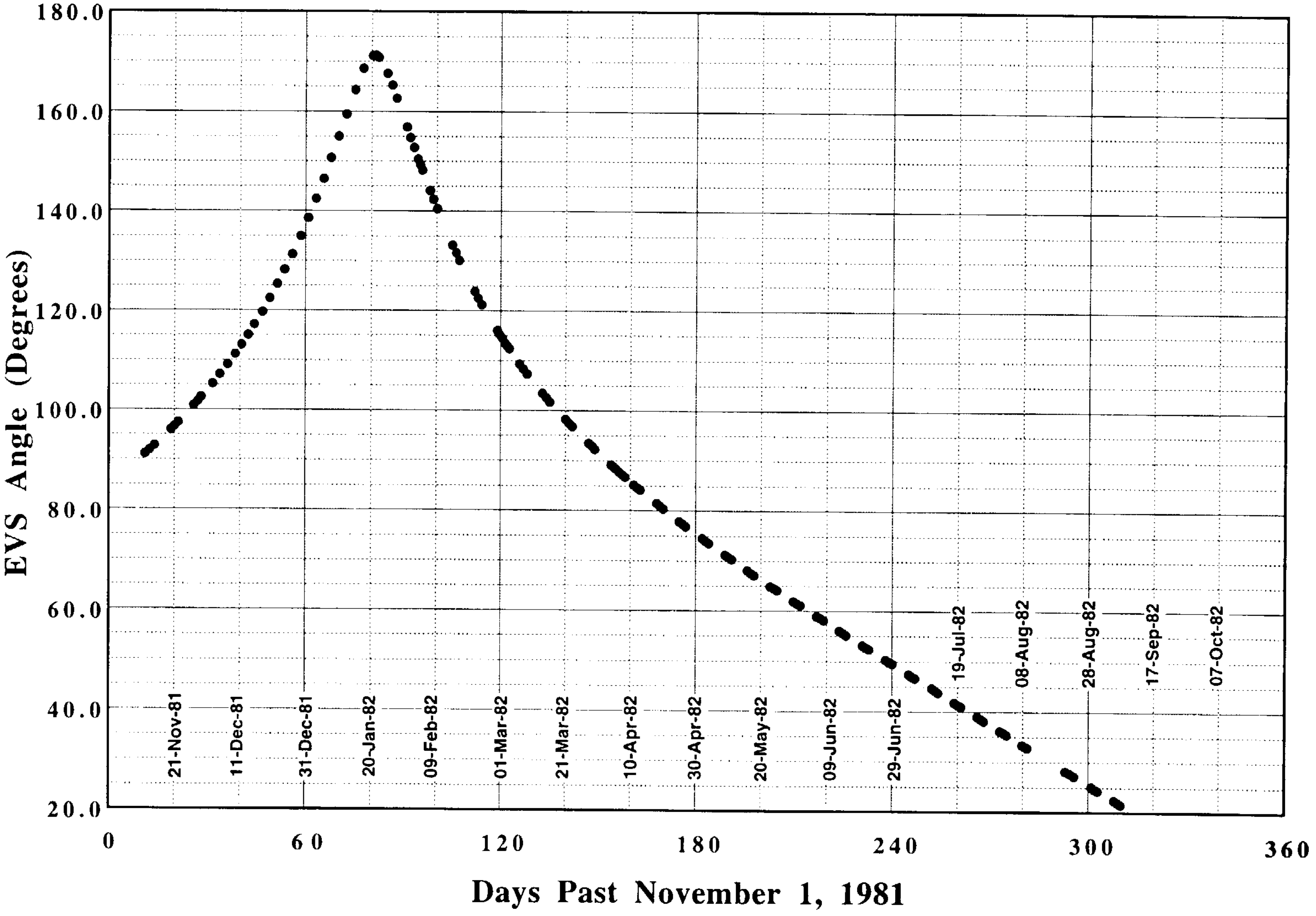
PVO High Orbit One-Way-Light-Time



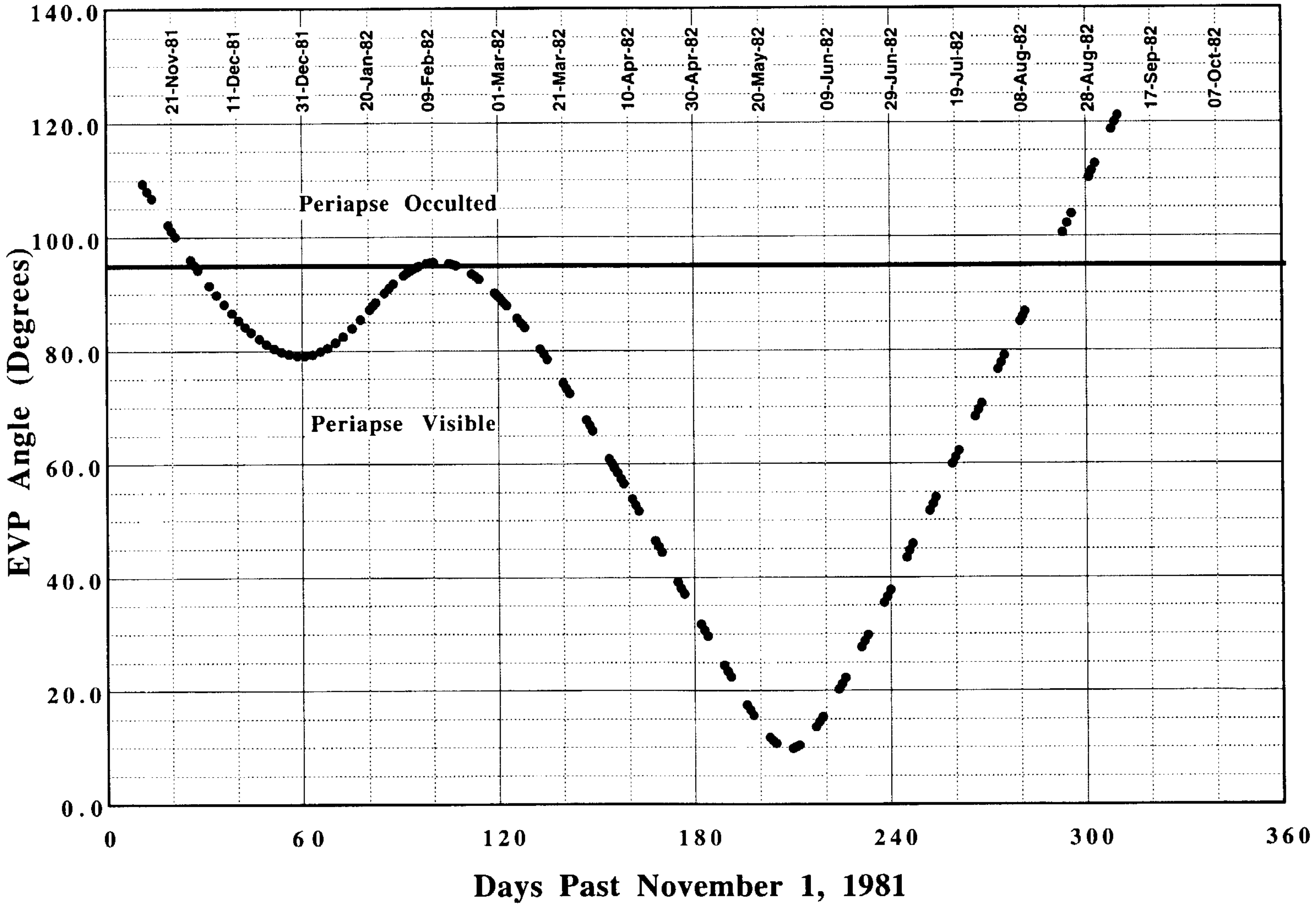
PVO High Orbit Sun-Earth-Venus Angle



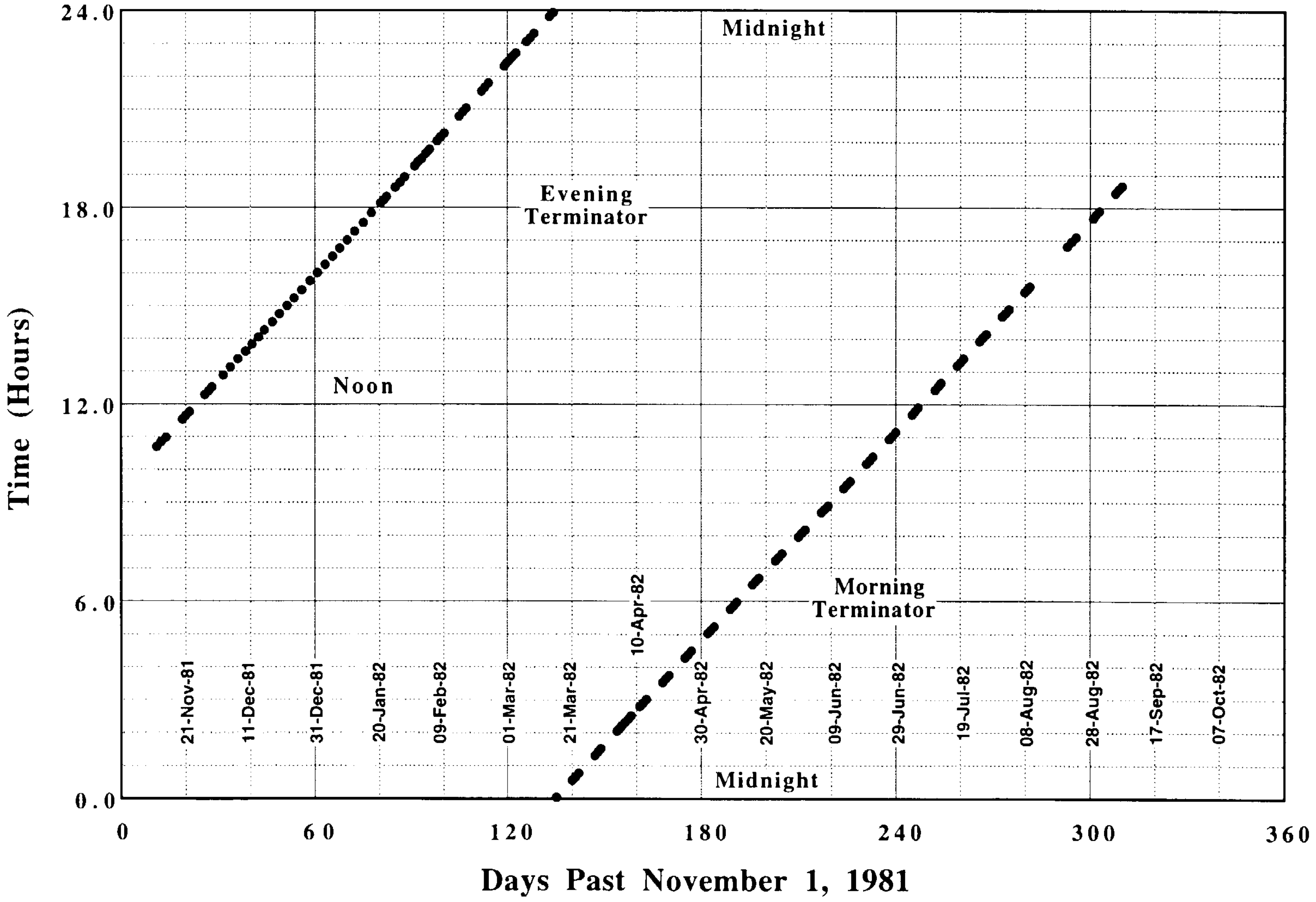
PVO High Orbit Earth-Venus-Sun Angle



PVO High Orbit Earth-Venus-Probe at Periapse Angle



PVO High Orbit Local Solar Time at Periapse



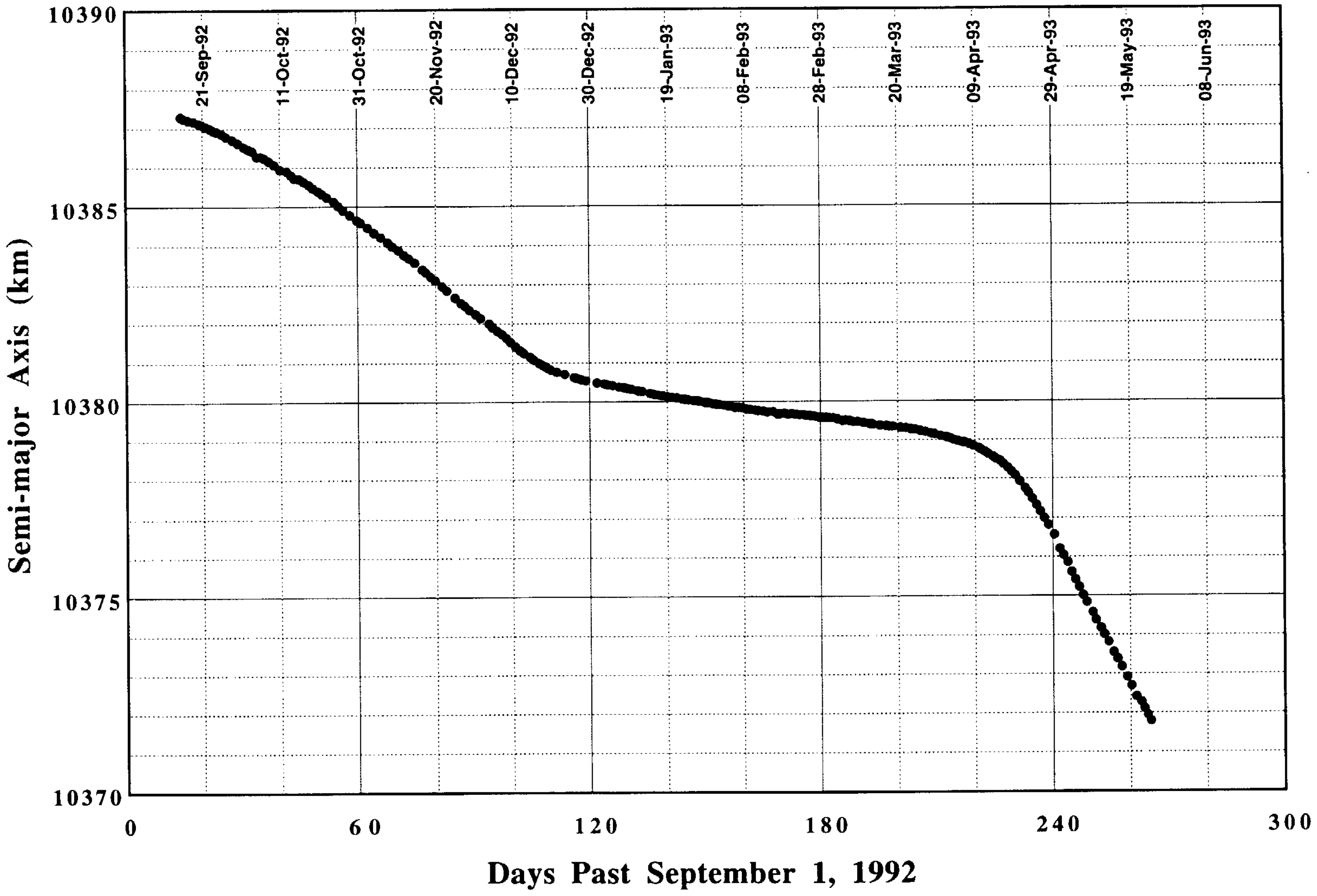
Appendix C

Magellan Cycle 4 (Elliptical) Information

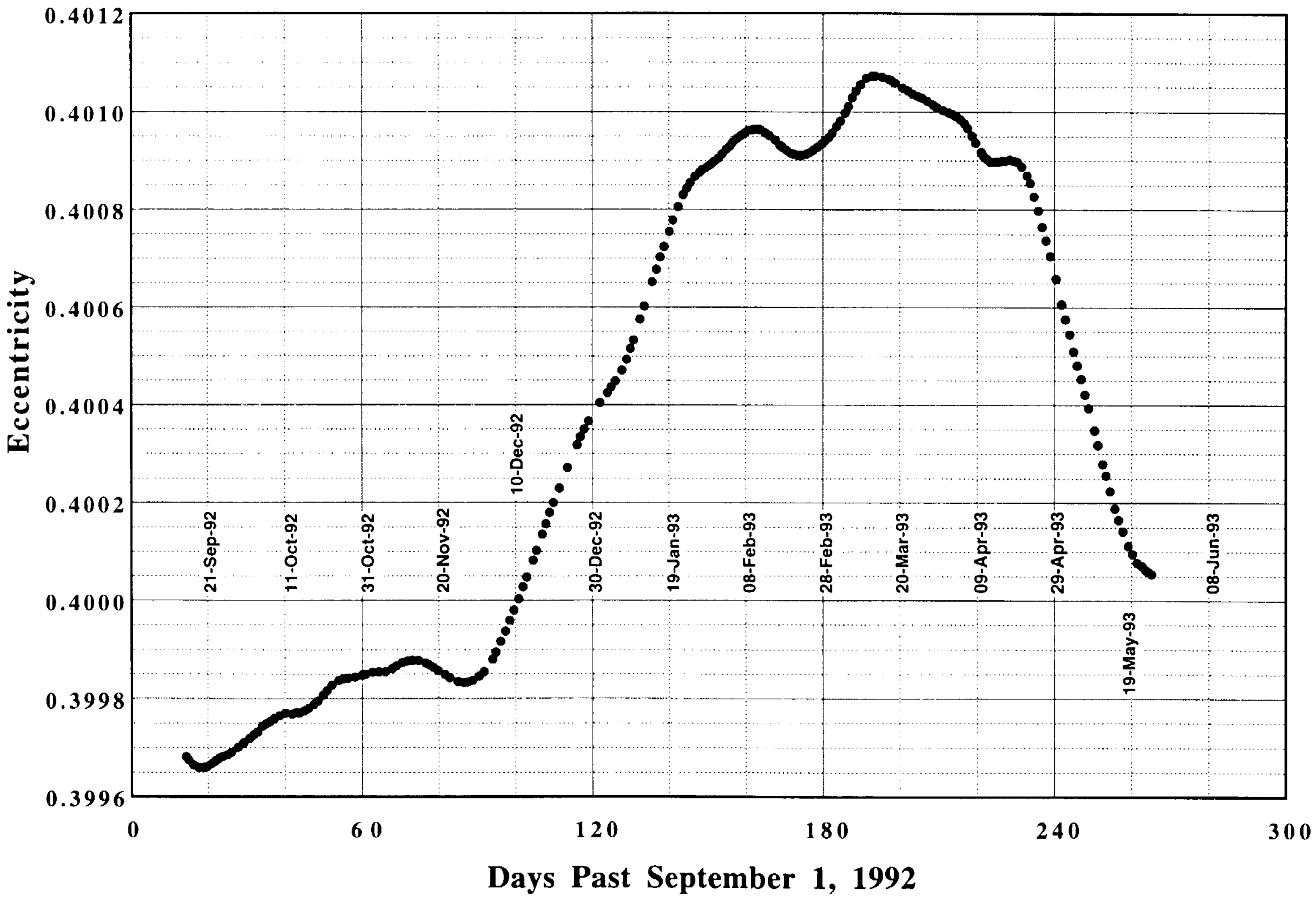
The following plots are included in this appendix:

1. Semi-major axis
2. Eccentricity
3. Inclination
4. Latitude at periapse
5. Longitude at periapse
6. Altitude at periapse
7. Plane-of-sky inclination vs time
8. Plane-of-sky inclination vs longitude
9. One-way light time from Venus to Earth
10. Sun-Earth-Venus angle
11. Earth-Venus-Probe at periapse angle
12. Local solar time at periapse
13. Altitude vs. latitude profile

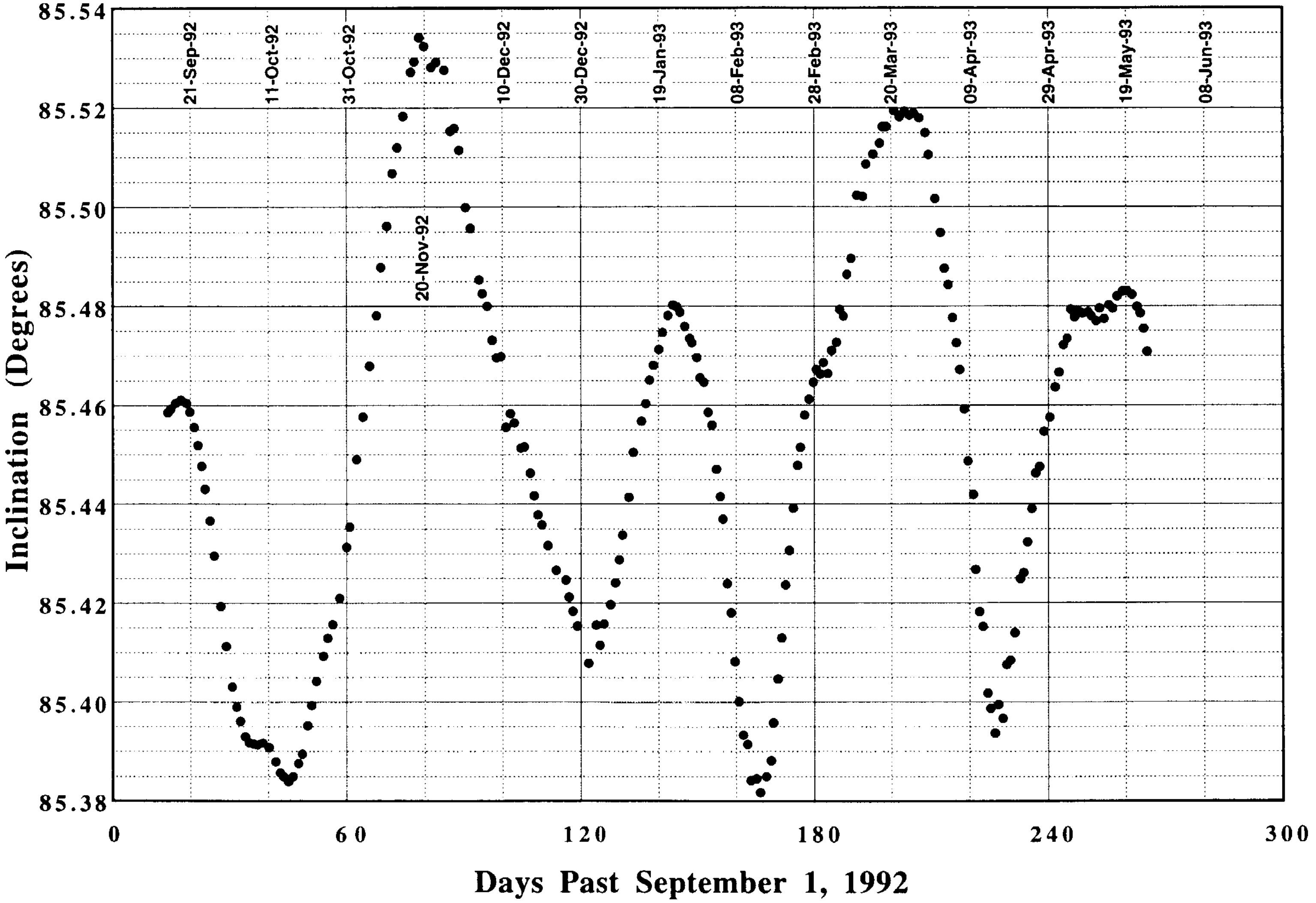
Magellan Cycle 4 Semi-Major Axis



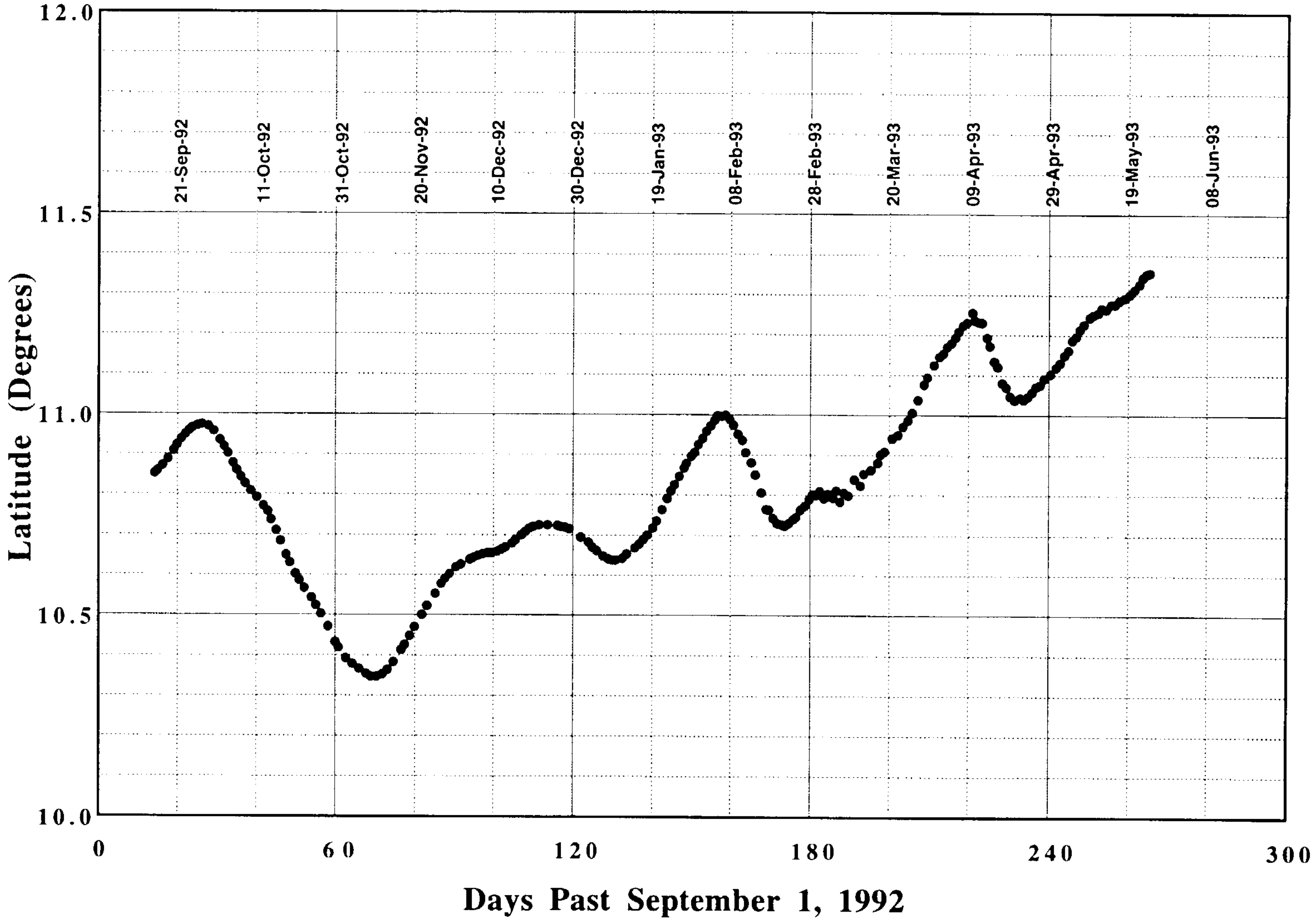
Magellan Cycle 4 Eccentricity



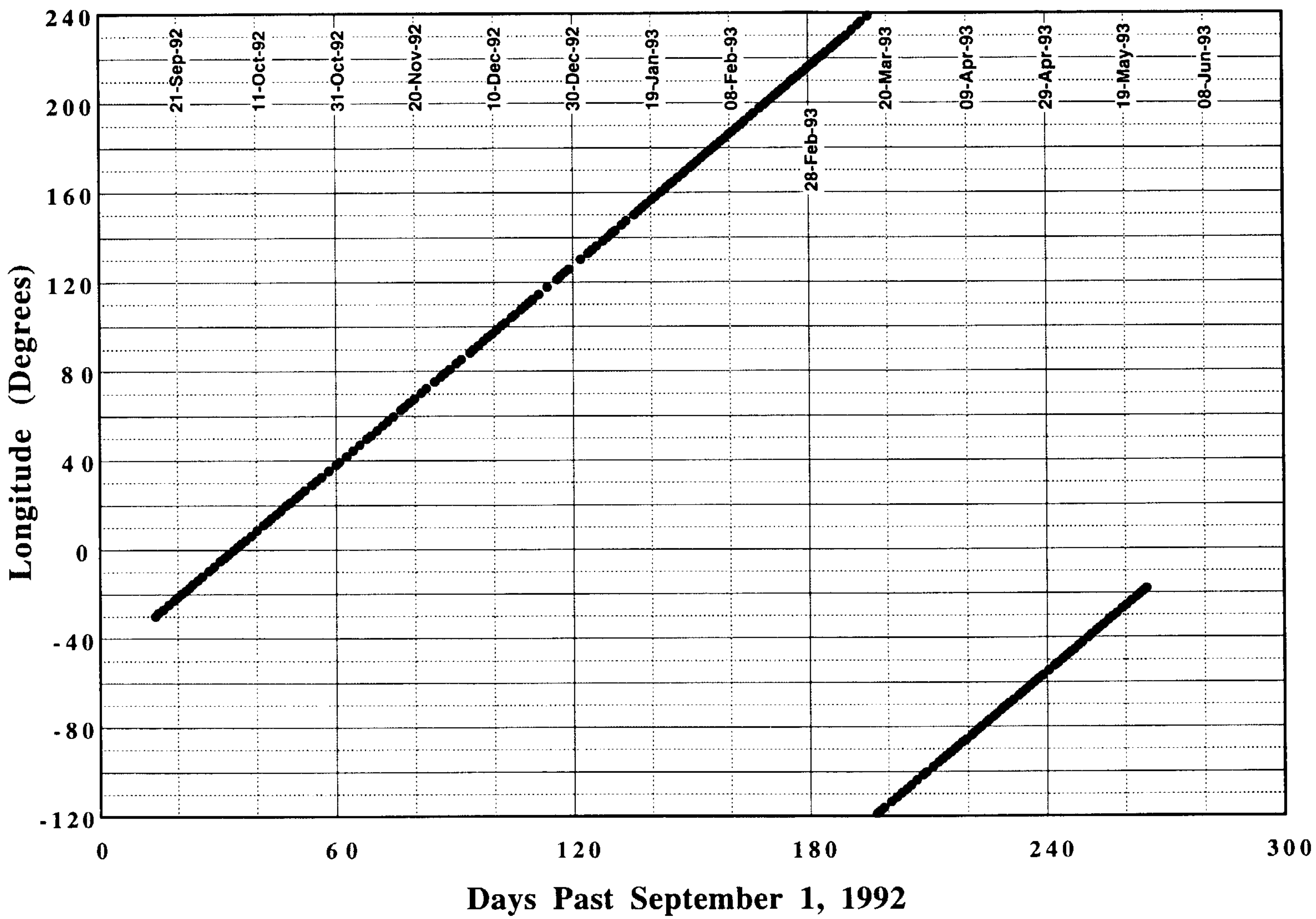
Magellan Cycle 4 Inclination



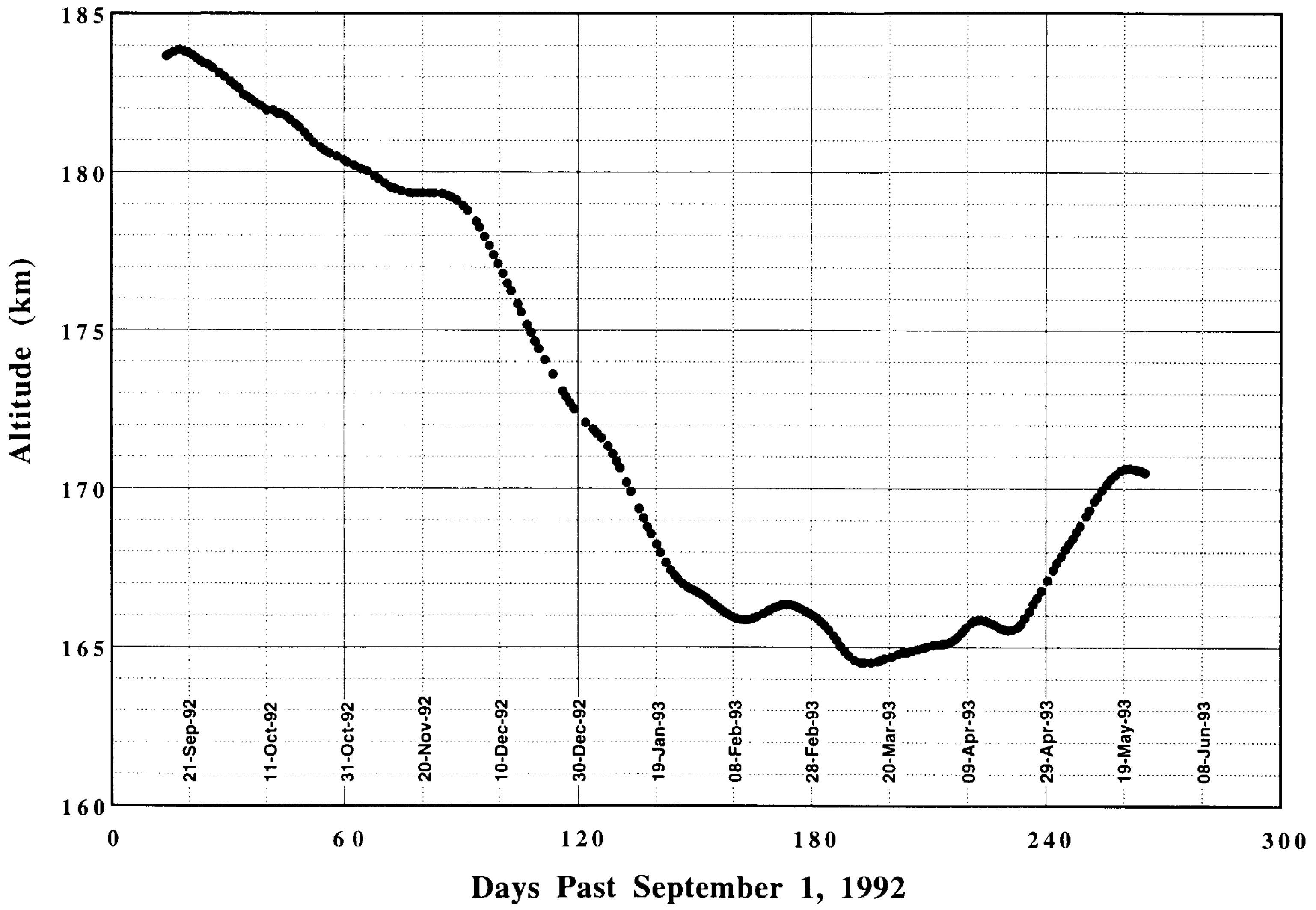
Magellan Cycle 4 Latitude at Periapse



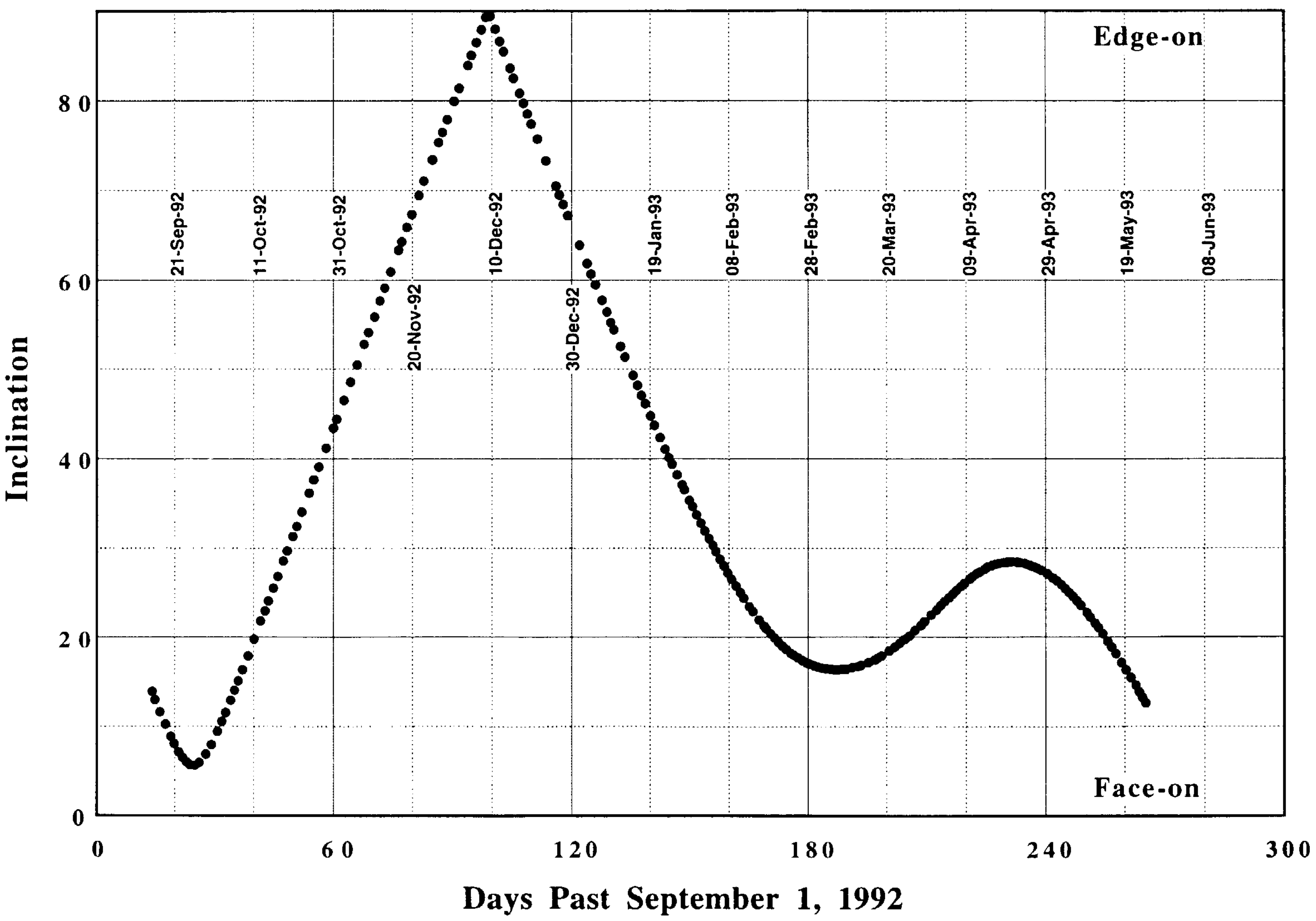
Magellan Cycle 4 Longitude at Periapse



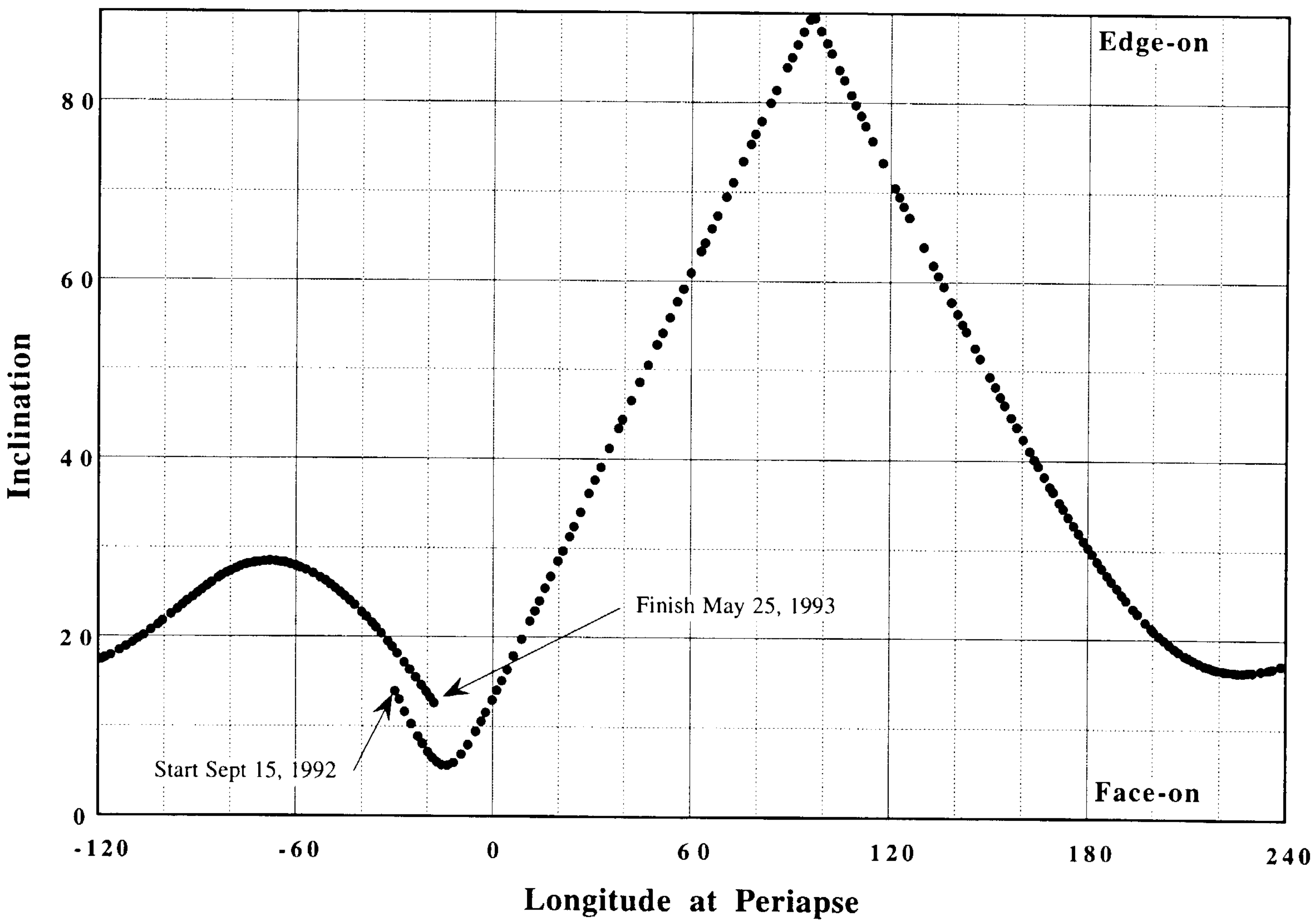
Magellan Cycle 4 Altitude at Periapse



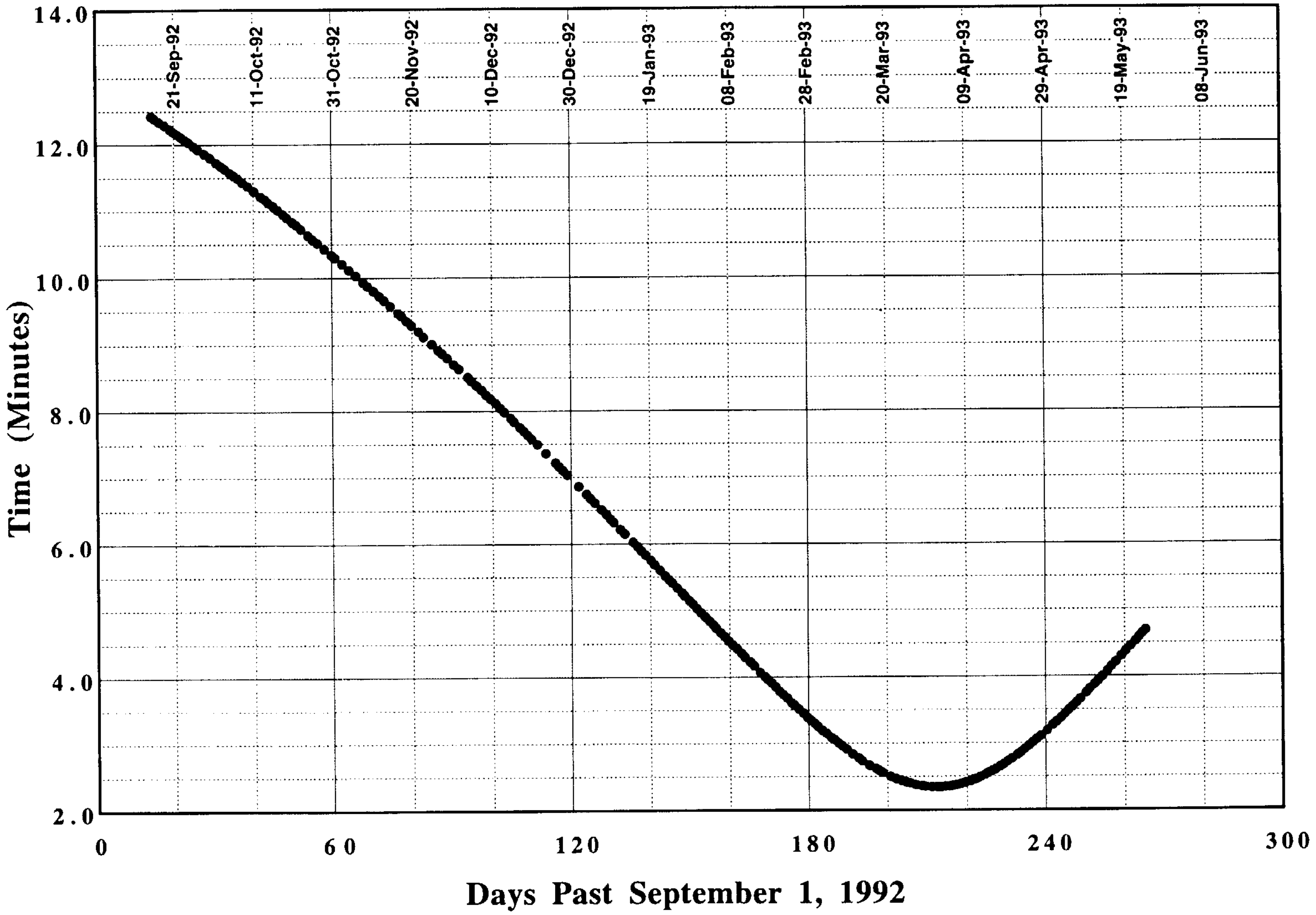
Magellan Cycle 4 Plane-of-Sky Inclination



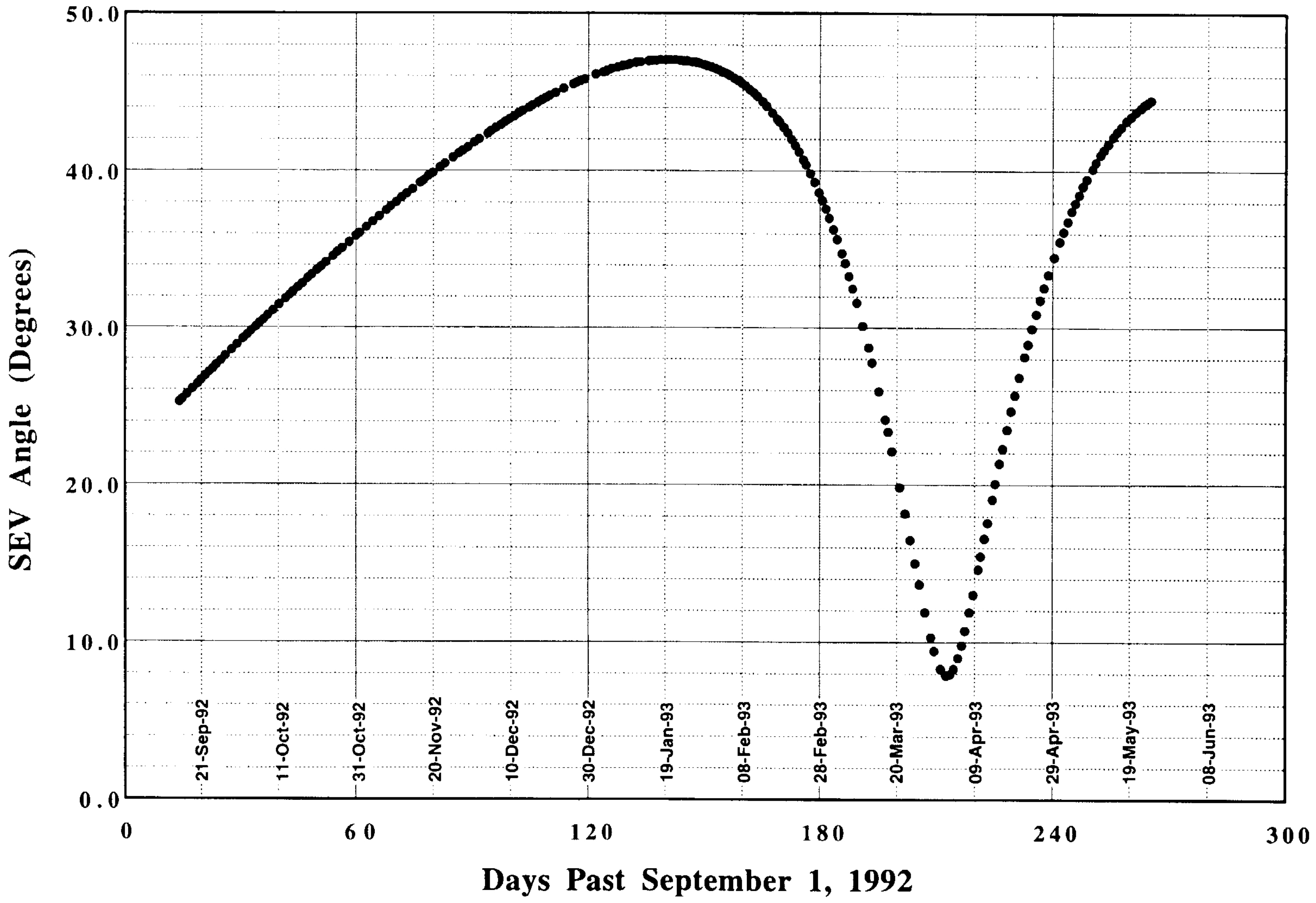
Magellan Cycle 4 Plane-of-Sky Inclination



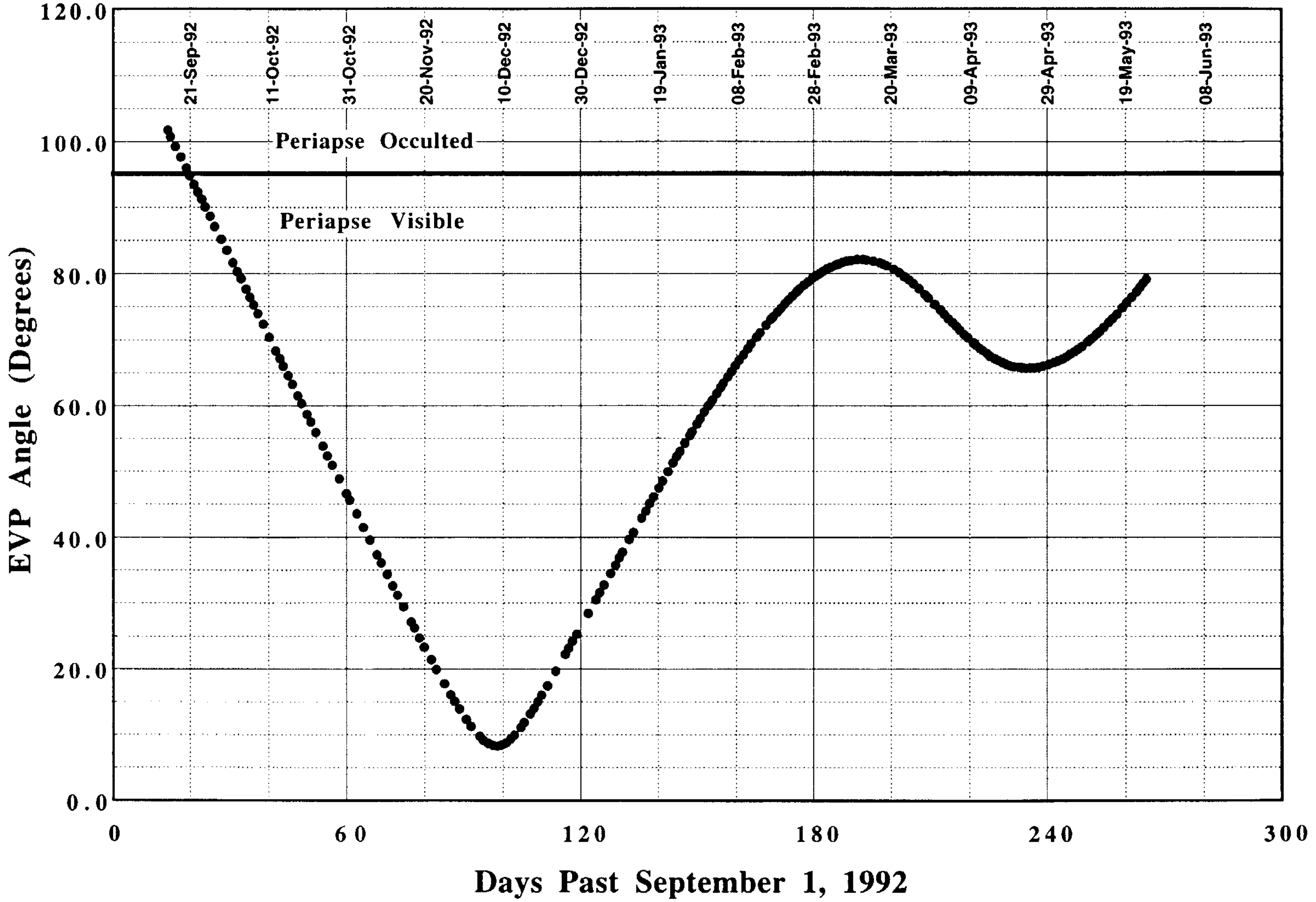
Magellan Cycle 4 One-Way-Light-Time



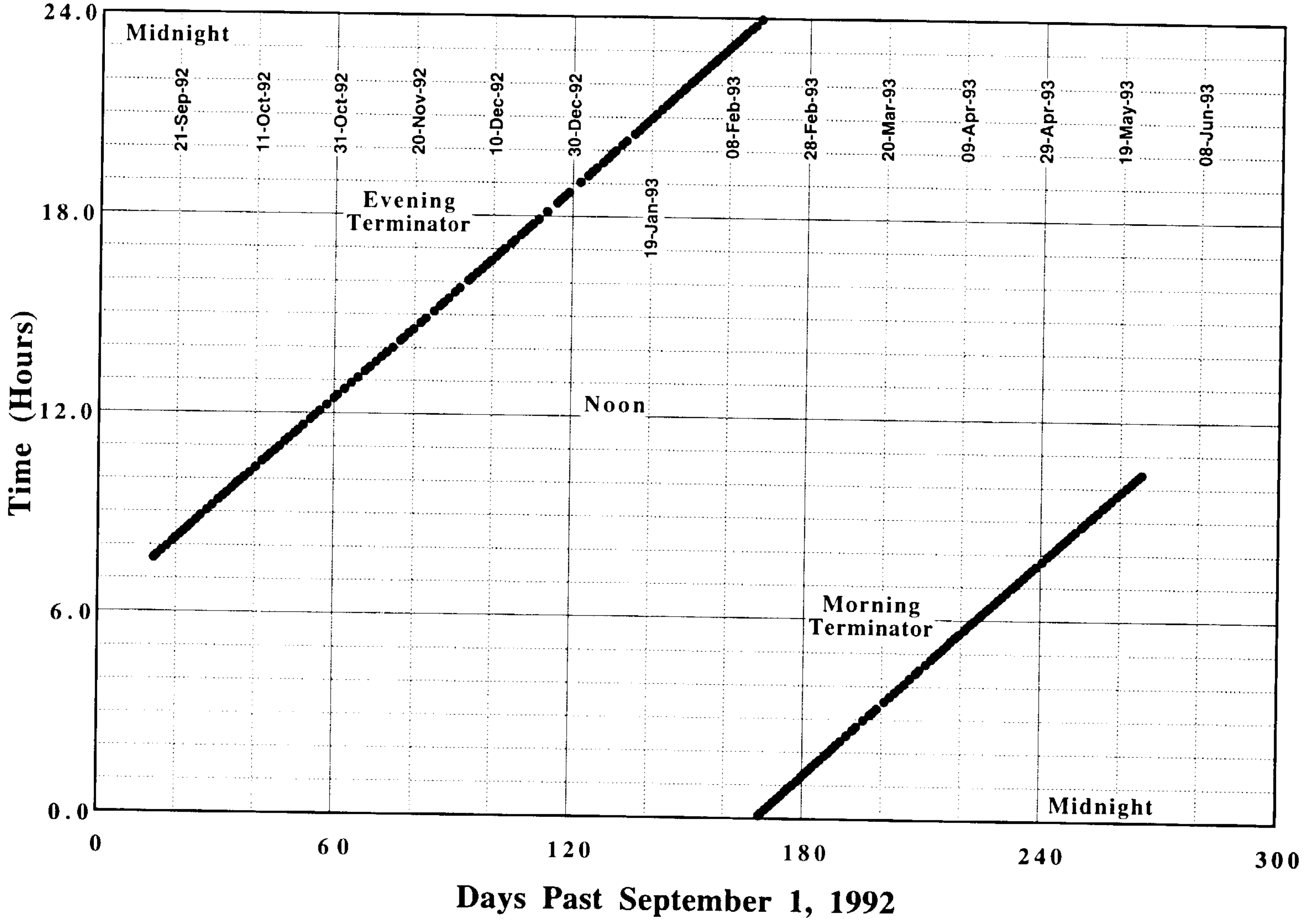
Magellan Cycle 4 Sun-Earth-Venus Angle



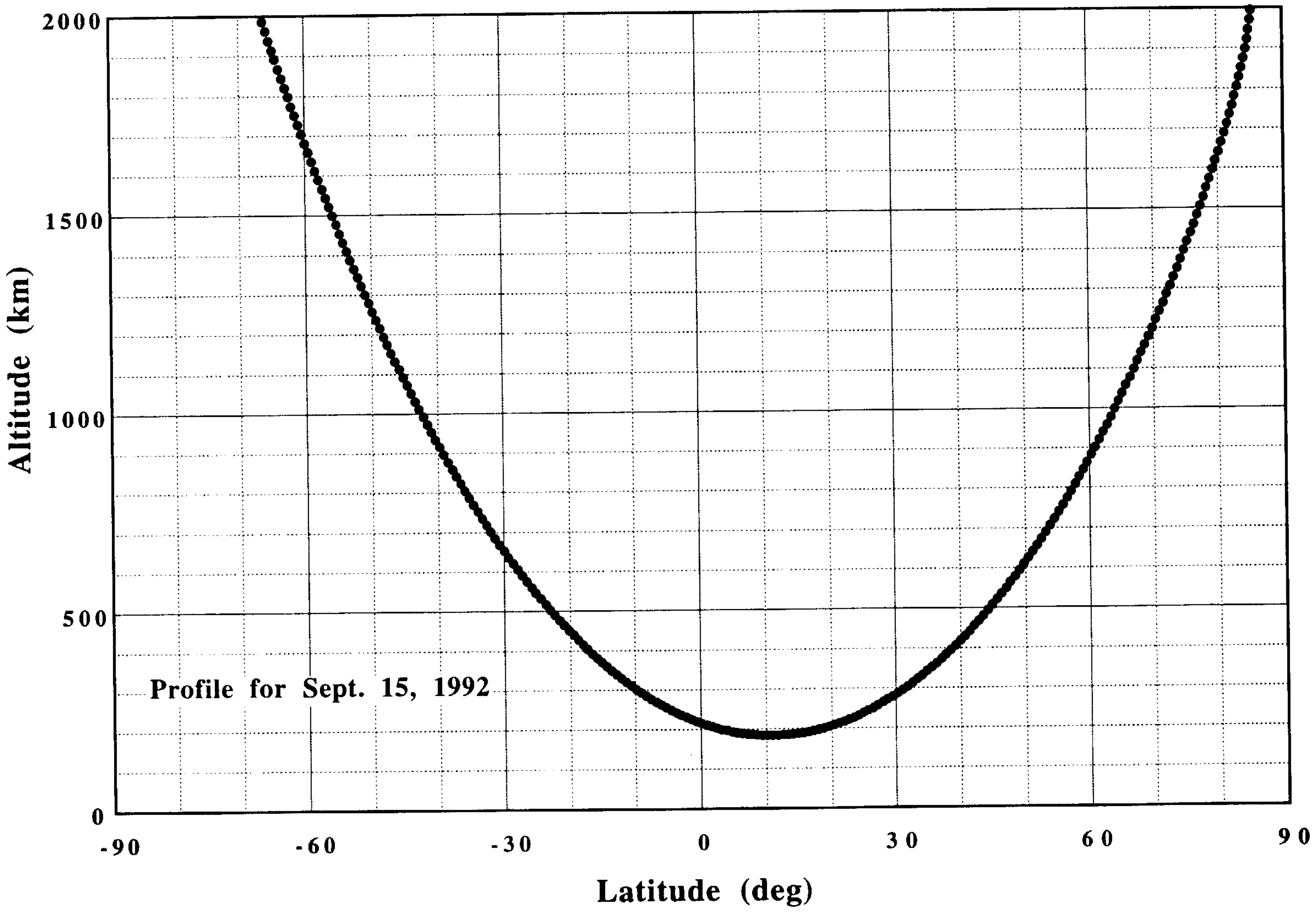
Magellan Cycle 4 Earth-Venus-Probe at Periapse Angle



Magellan Cycle 4 Local Solar Time at Periapse



Magellan Cycle 4 Altitude vs Latitude



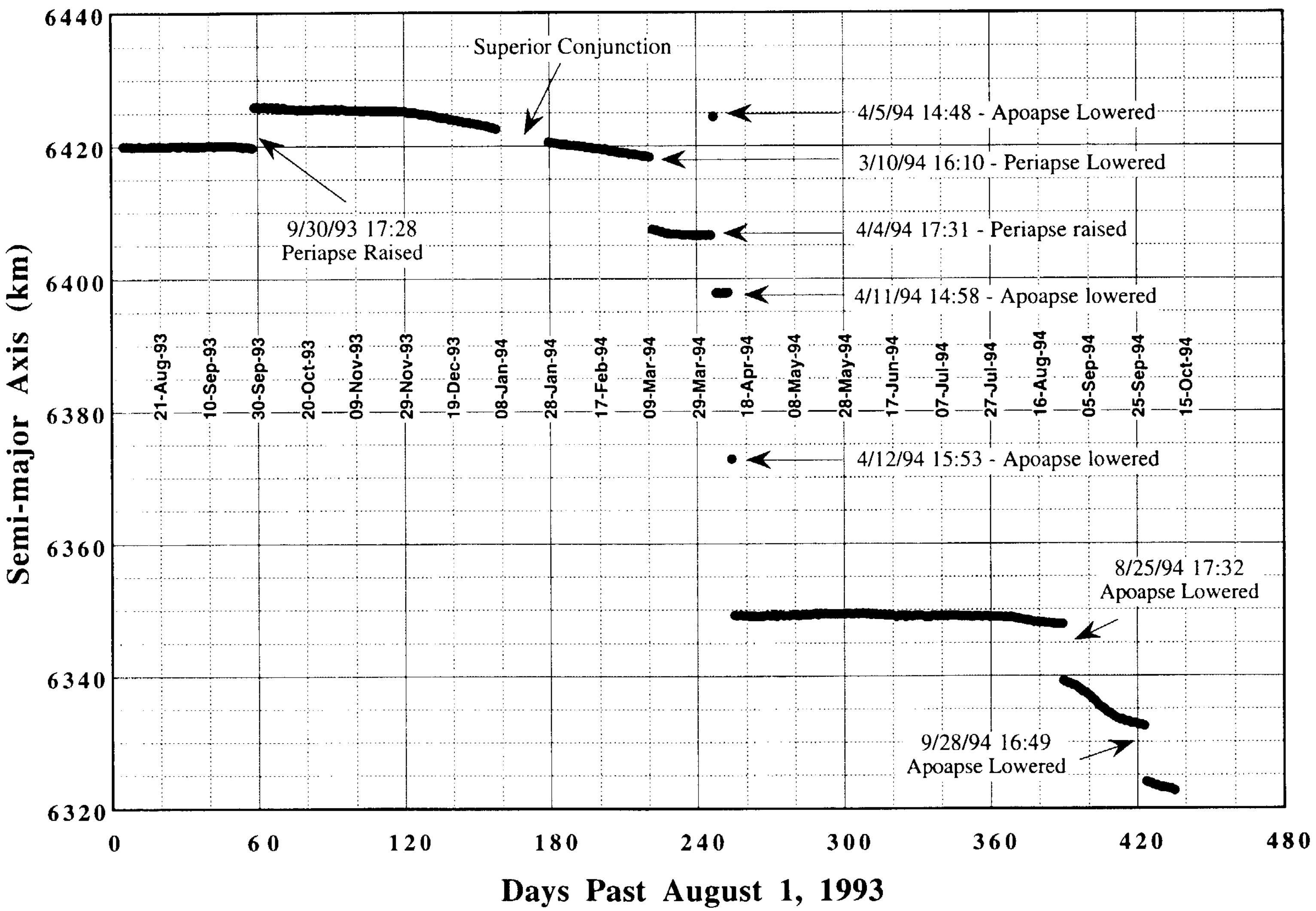
Appendix D

Magellan Cycle 5 and 6 (Circular) Information

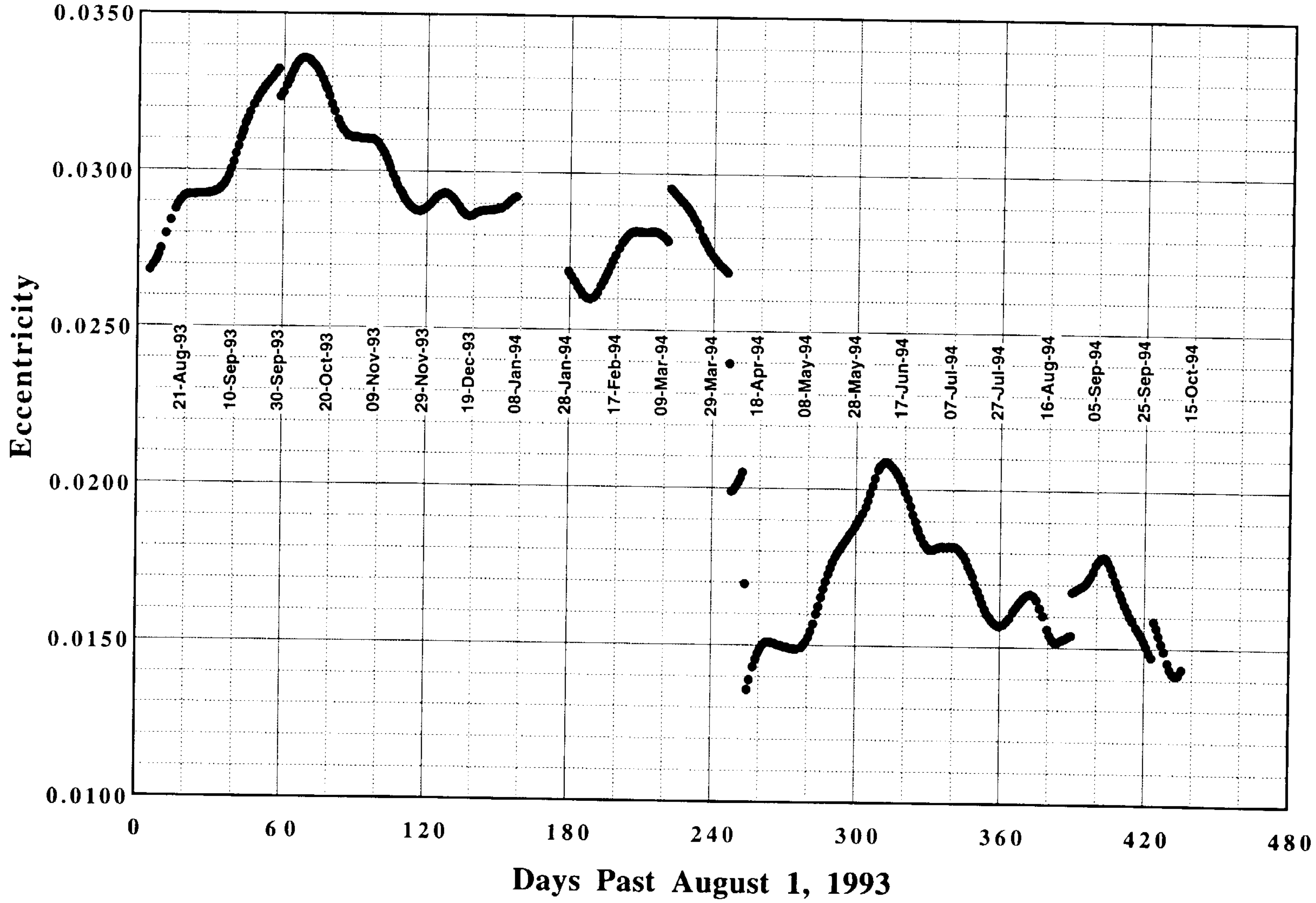
The following plots are included in this appendix:

1. Semi-major axis
2. Eccentricity
3. Inclination
4. Latitude at periapse
5. Longitude at periapse
6. Altitude at periapse
7. Altitude at apoapse
8. Plane-of-sky inclination vs time
9. Plane-of-sky inclination vs longitude
10. One-way light time from Venus to Earth
11. Sun-Earth-Venus angle
12. Earth-Venus-Probe at periapse angle
13. Local solar time at periapse
14. Altitude vs. latitude profile

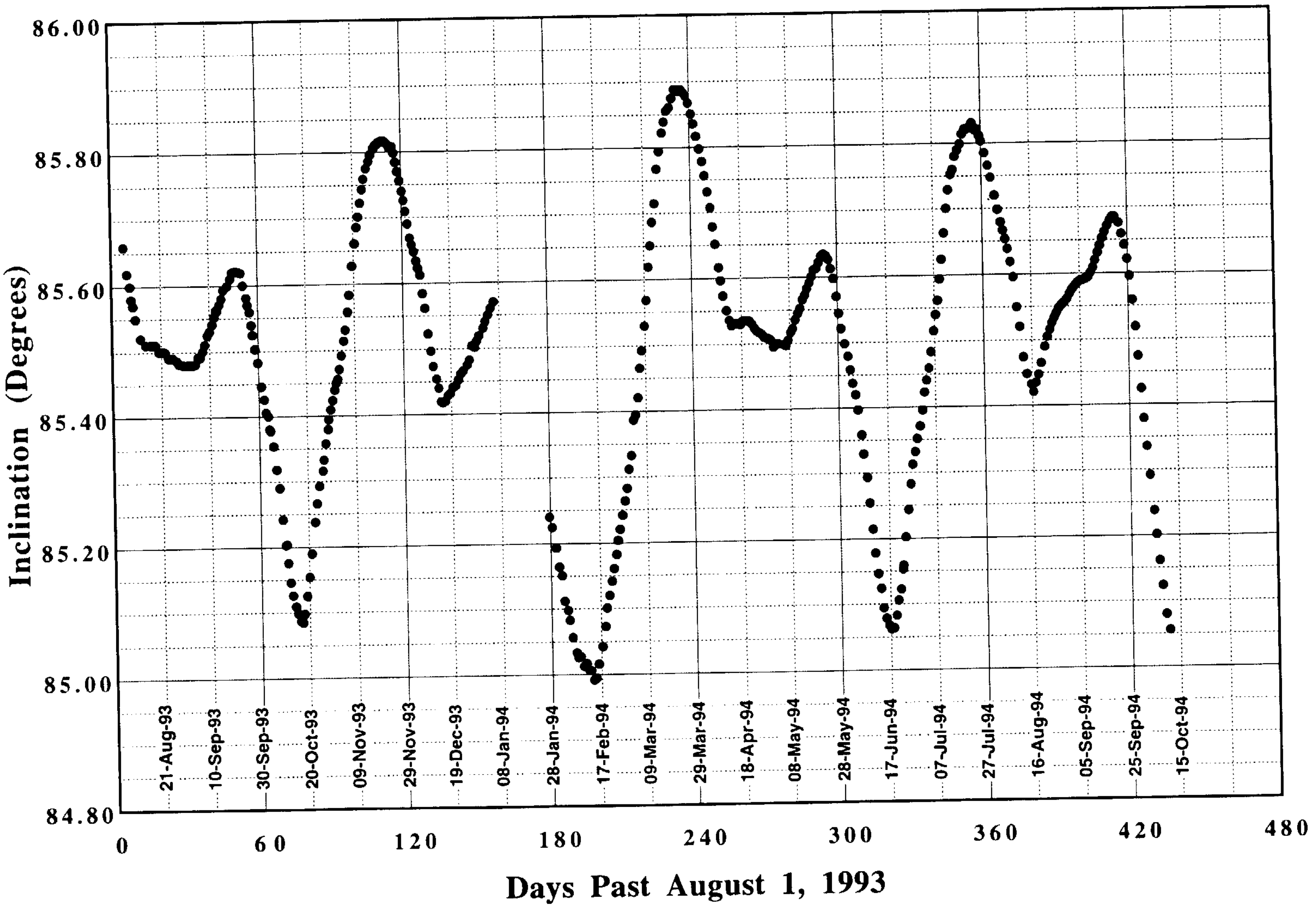
Magellan Cycle 5&6 Semi-Major Axis



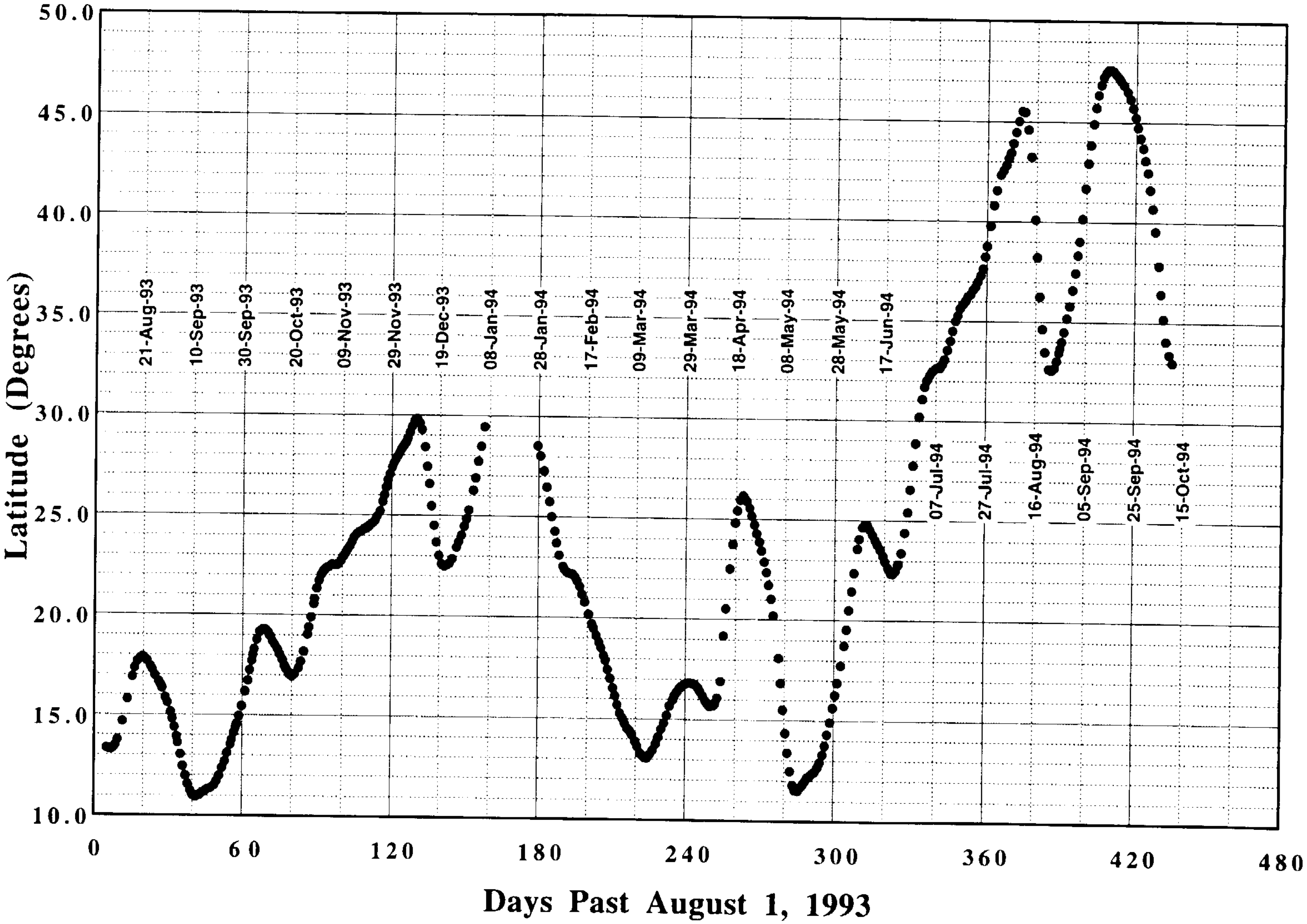
Magellan Cycle 5&6 Eccentricity



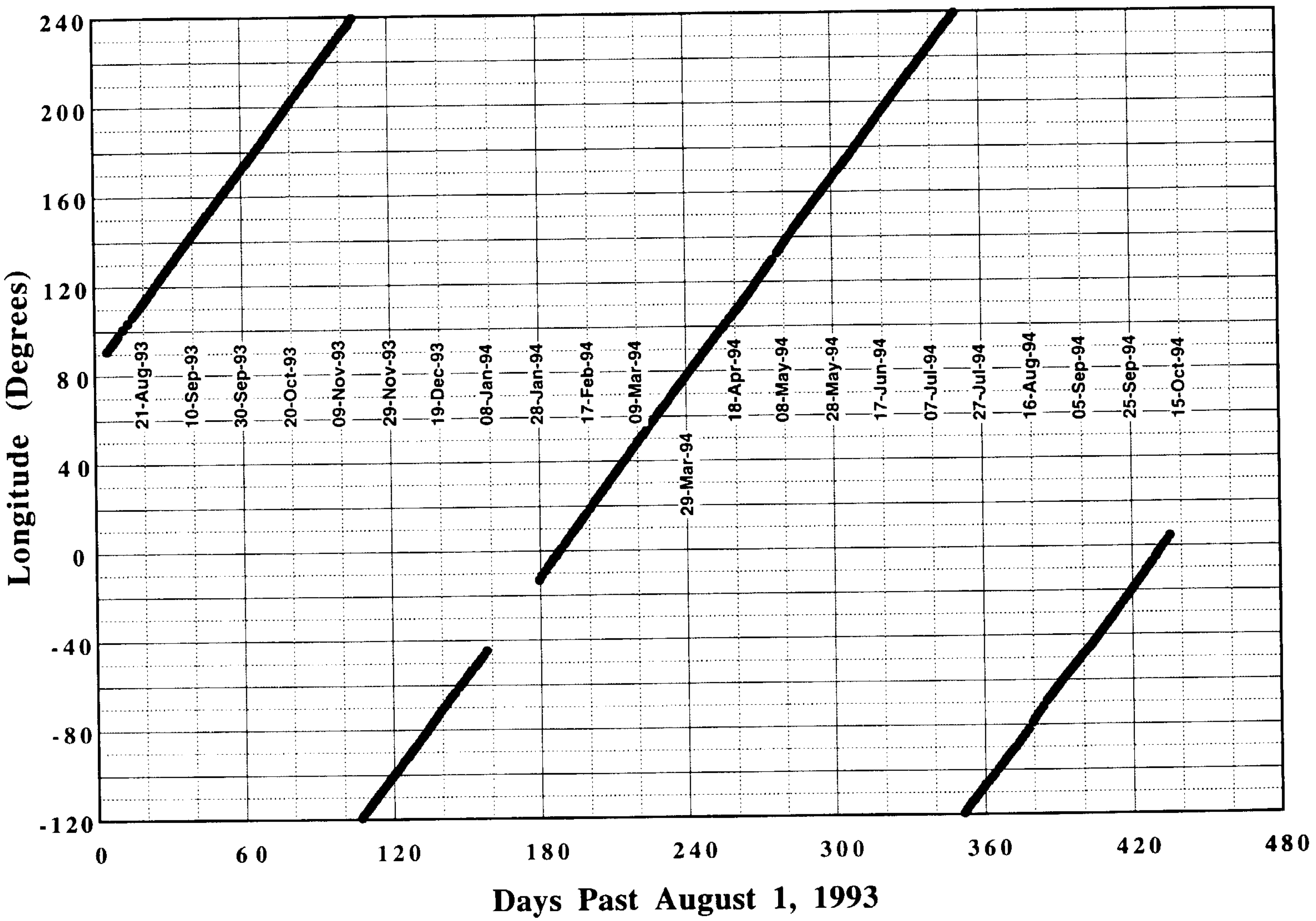
Magellan Cycle 5&6 Inclination



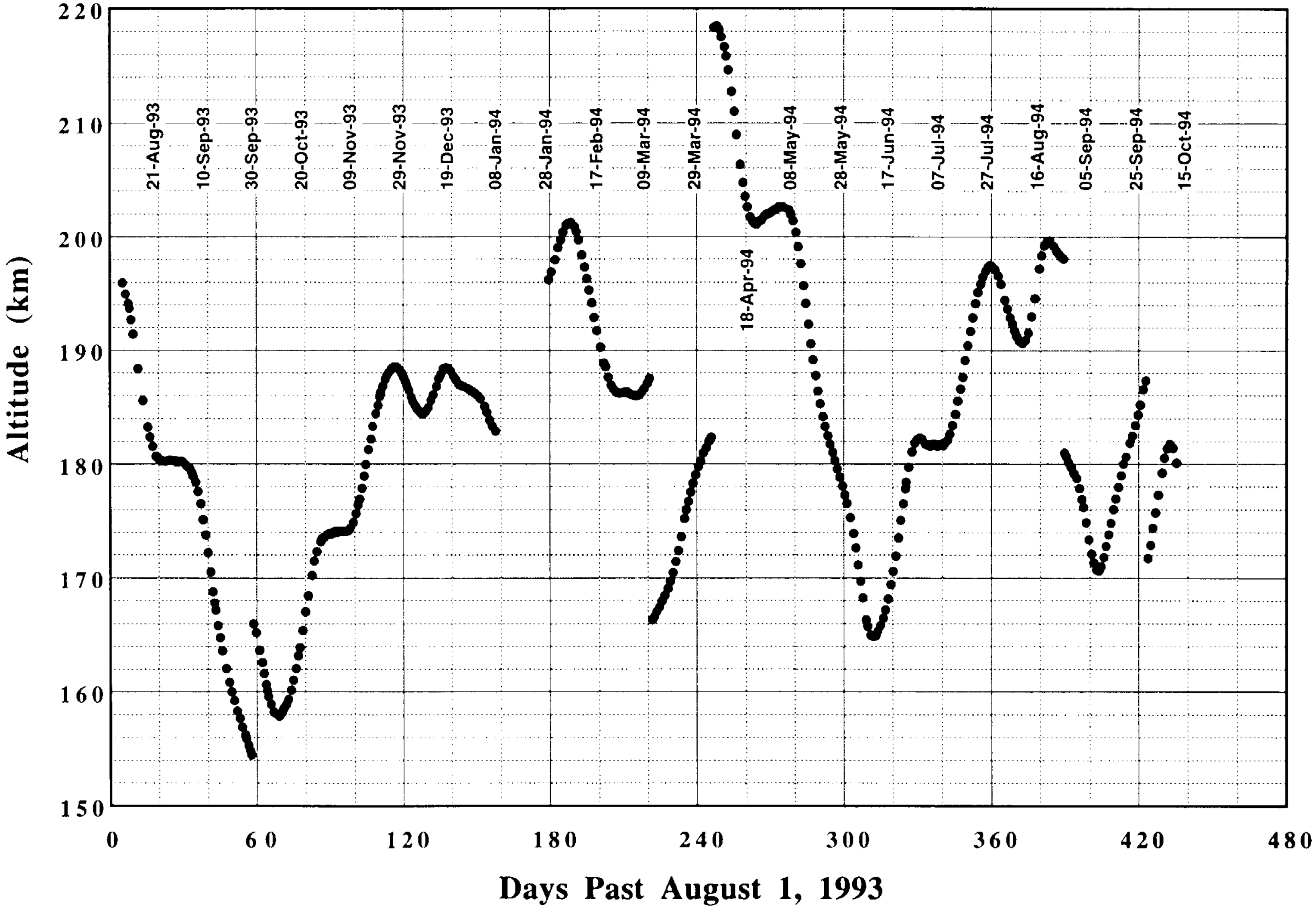
Magellan Cycle 5&6 Latitude at Periapse



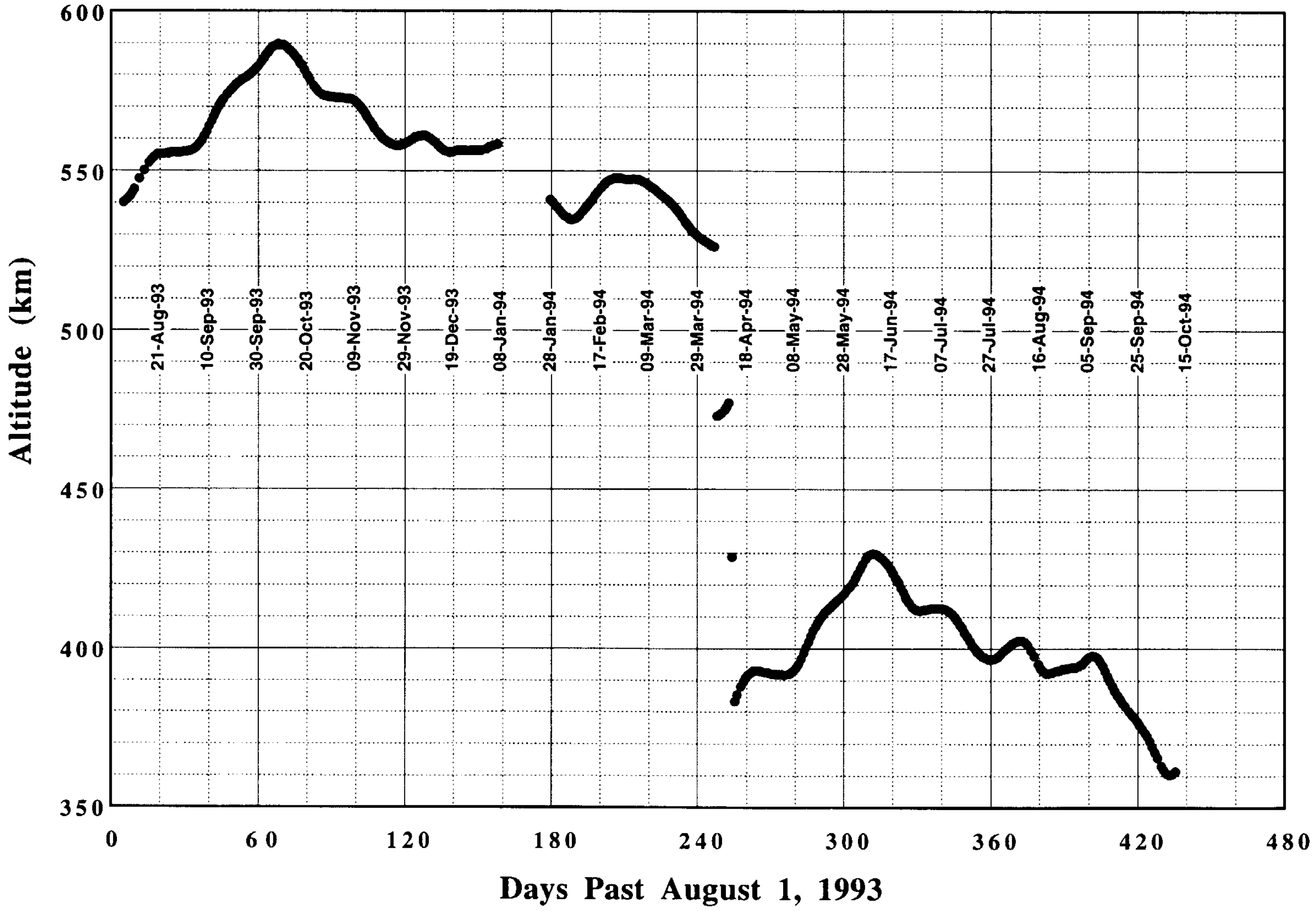
Magellan Cycle 5&6 Longitude at Periapse



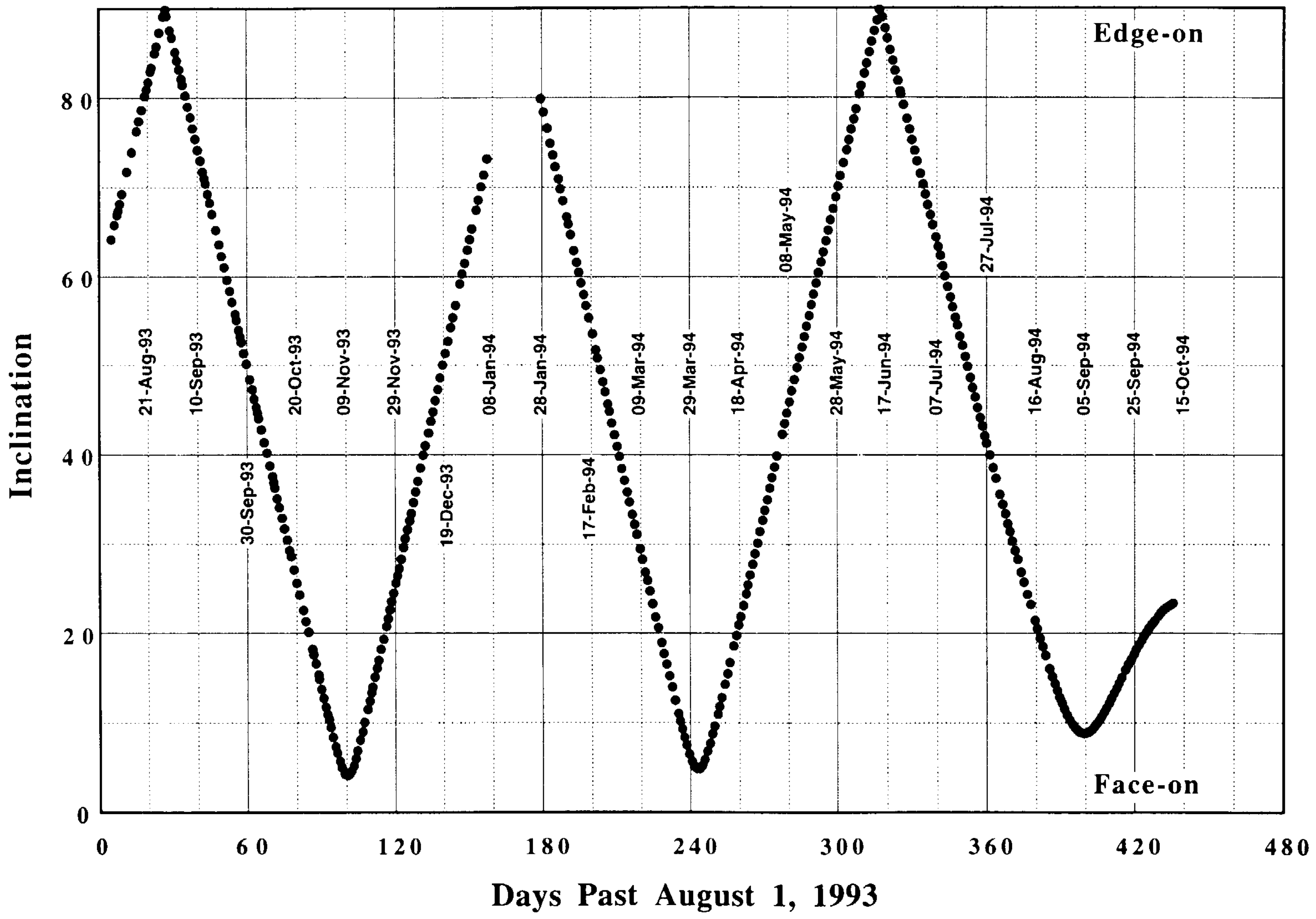
Magellan Cycle 5&6 Altitude at Periapse



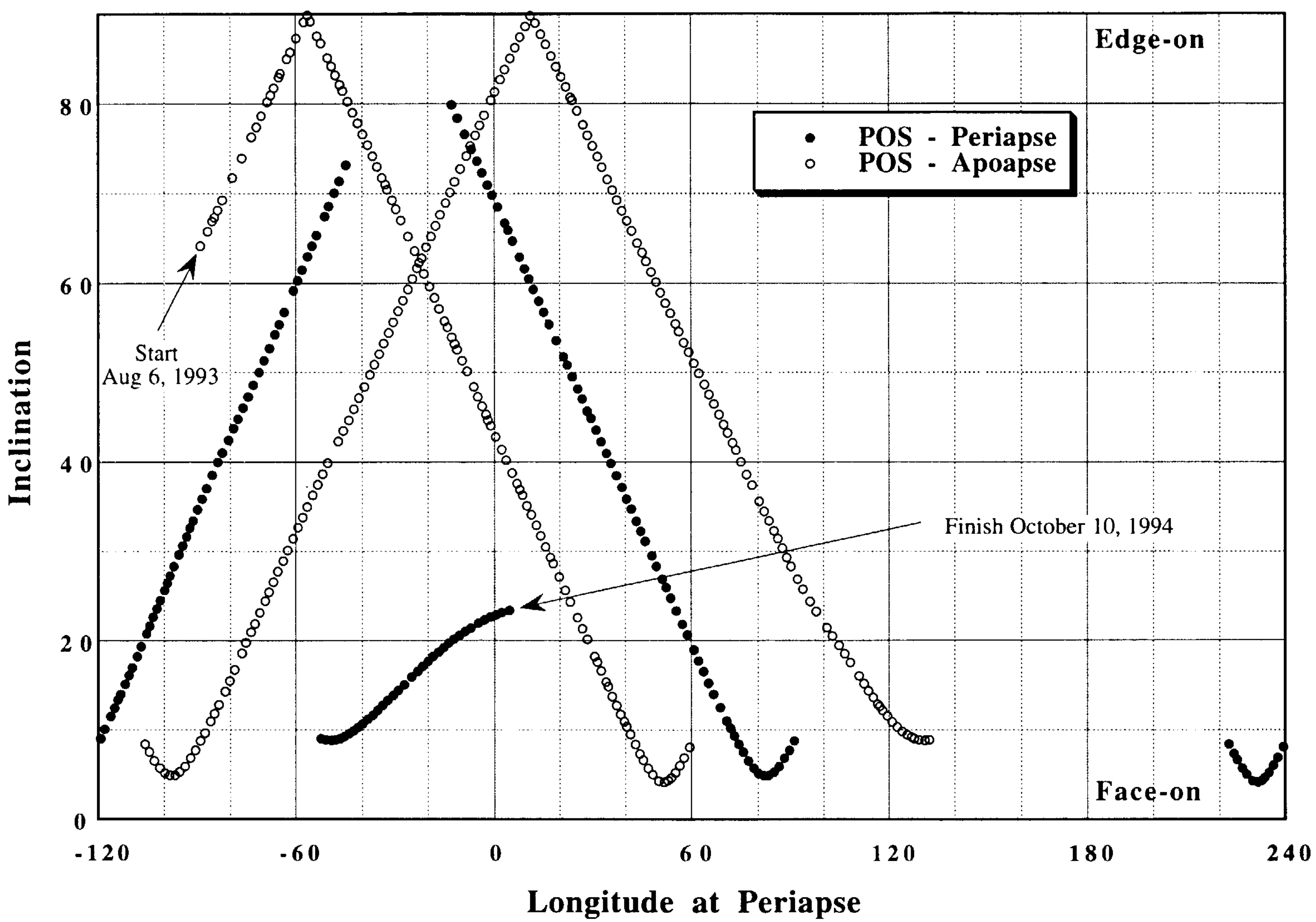
Magellan Cycle 5&6 Altitude at Apoapse



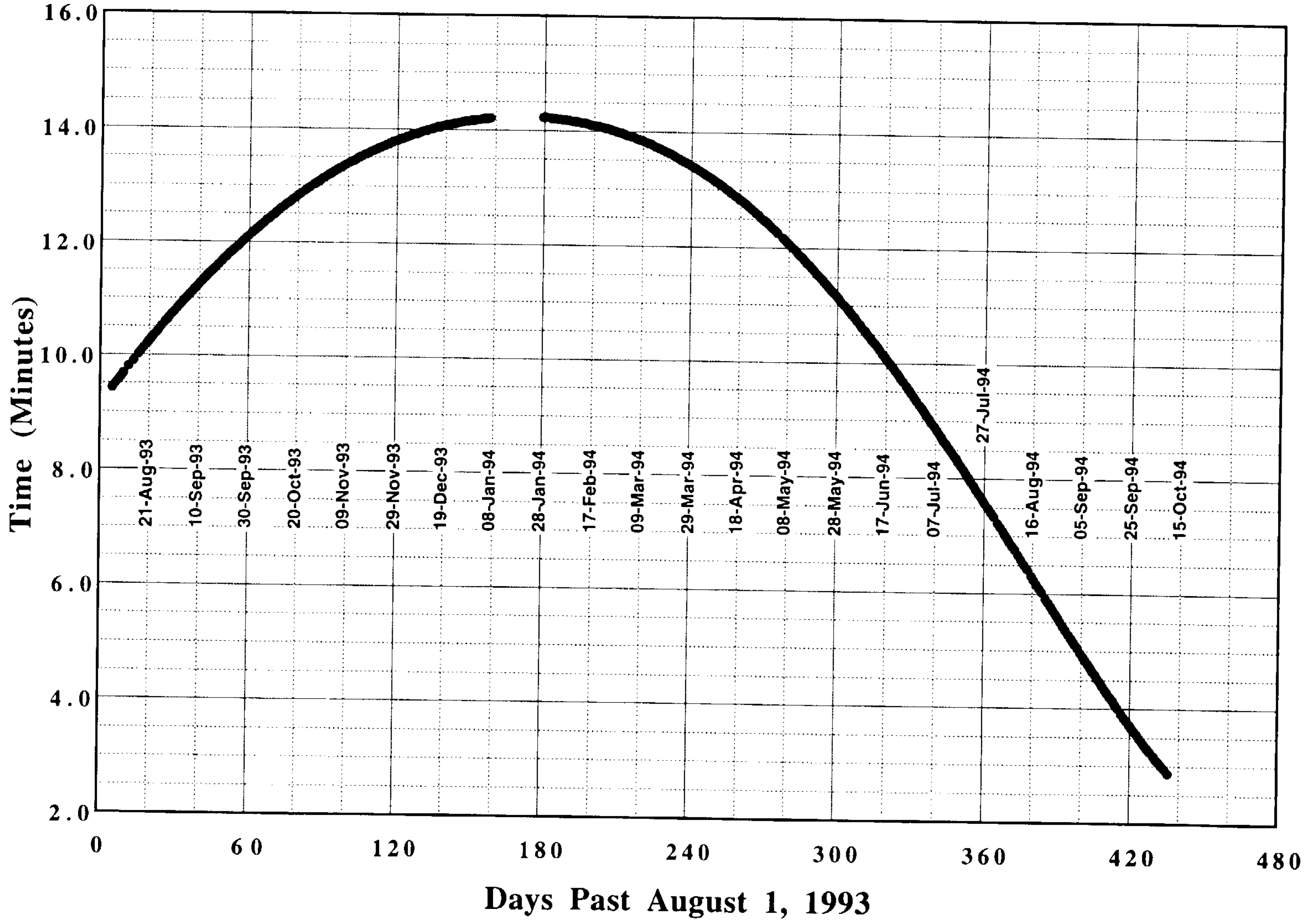
Magellan Cycle 5&6 Plane-of-Sky Inclination



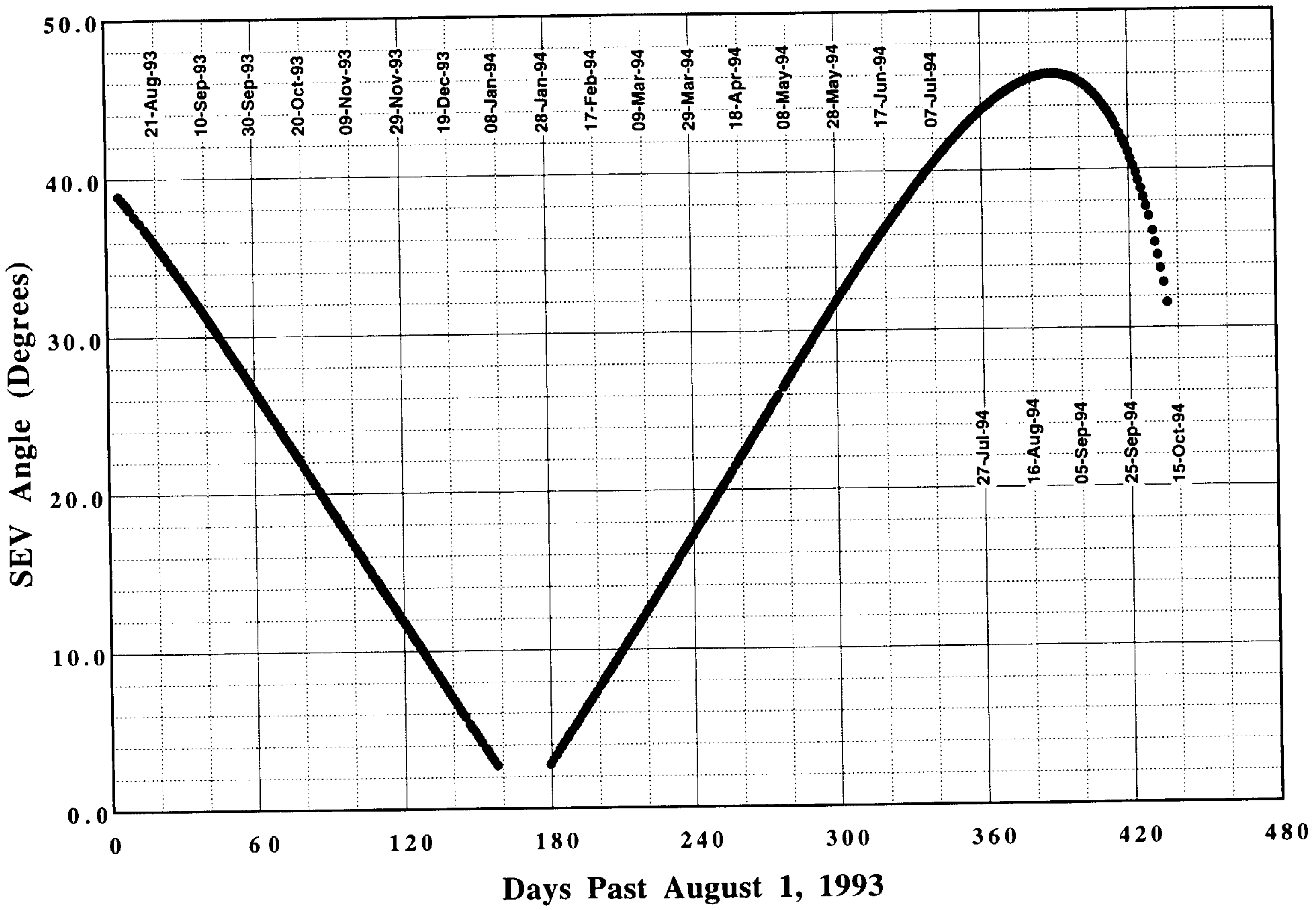
Magellan Cycle 5&6 Plane-of-Sky Inclination



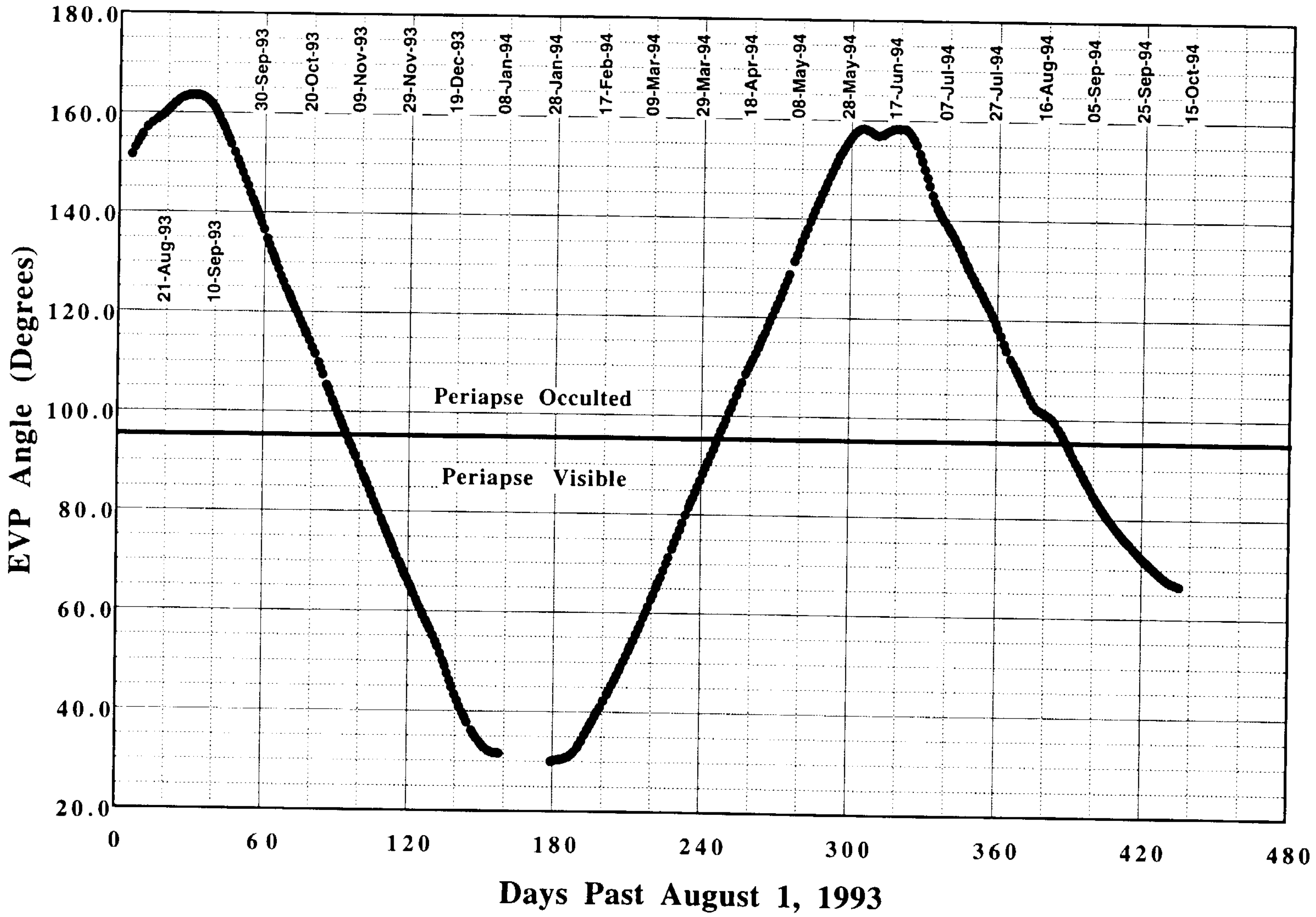
Magellan Cycle 5&6 One-Way-Light-Time



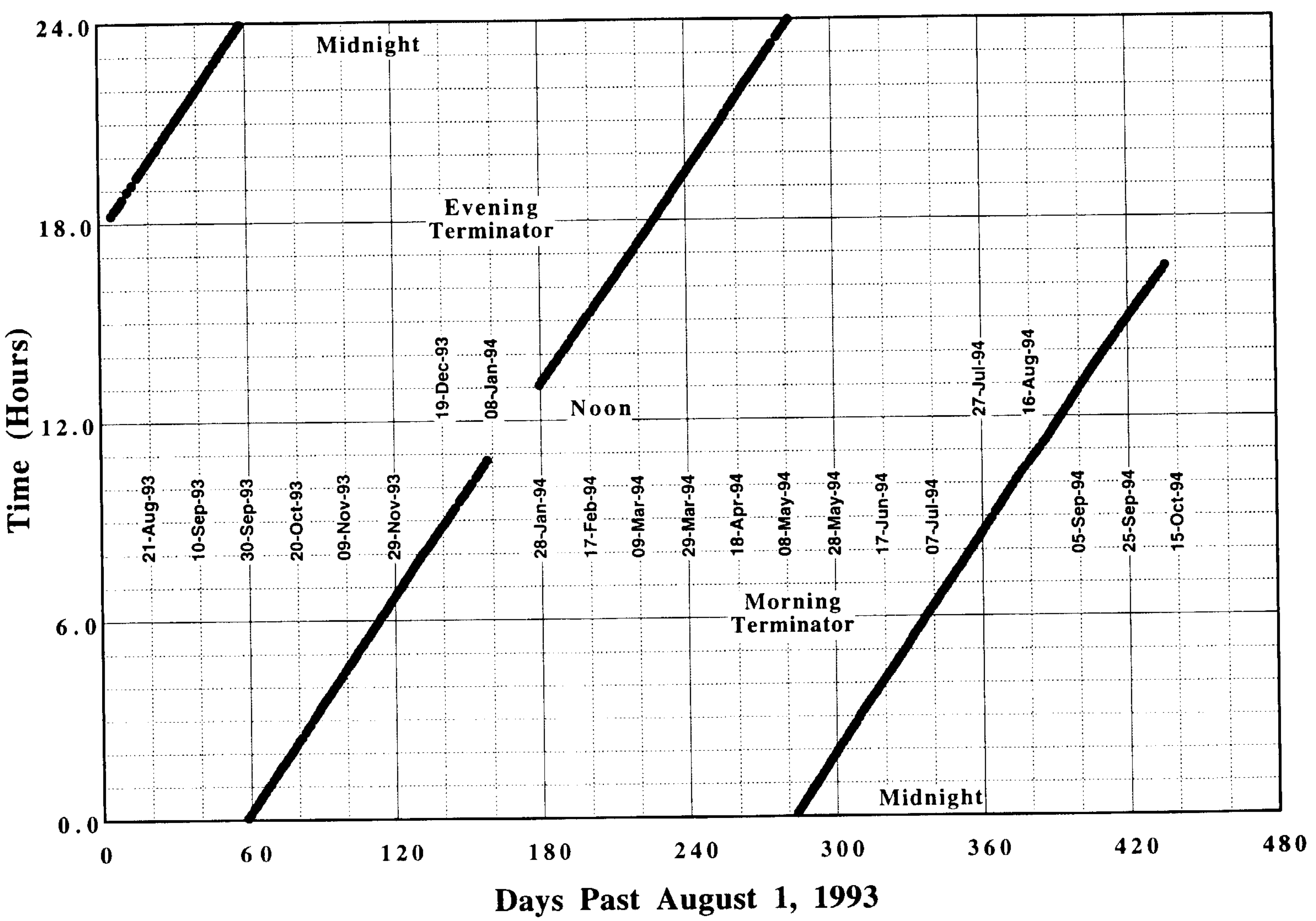
Magellan Cycle 5&6 Sun-Earth-Venus Angle



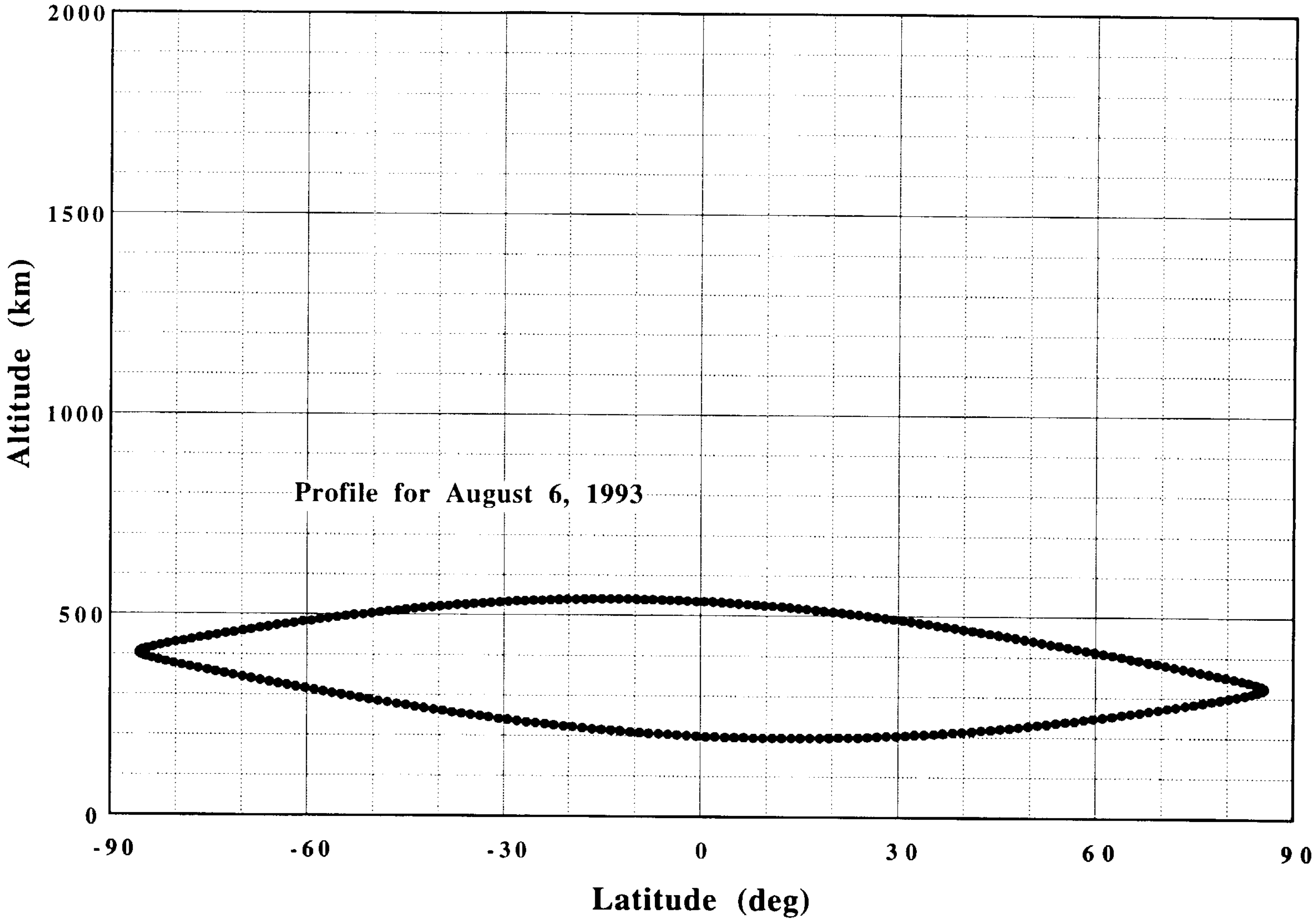
Magellan Cycle 5&6 Earth-Venus-Probe at Periapse Angle



Magellan Cycle 5&6 Local Solar Time at Periapse



Magellan Cycle 5&6 Altitude vs Latitude



Appendix E

Magellan X-band Orbit Information

The columns contain the following information (in order):

1. Orbit number
2. Tracking data file name ("_2" is 2 second data and "_10" is 10 second data)
3. Number of Doppler observations
4. Tracking station number (15=Goldstone, 45=Canberra, 65=Madrid)
5. Time of first observation

5757	92258j261_10	878	65	15-SEP-1992	12:35:35
5758	92258j261_10	756	65	15-SEP-1992	15:50:05
5760	92258j261_10	836	45	15-SEP-1992	22:59:45
5761	92258j261_10	872	45	16-SEP-1992	01:33:35
5762	92258j261_10	852	45	16-SEP-1992	04:48:05
5763	92258j261_10	268	45	16-SEP-1992	08:02:35
5764	92258j261_10	338	65	16-SEP-1992	13:20:55
5765	92258j261_10	707	65	16-SEP-1992	14:31:35
5767	92258j261_10	2	45	17-SEP-1992	00:05:45
5768	92258j261_10	10	45	17-SEP-1992	03:20:30
5769	92258j261_10	847	45	17-SEP-1992	03:30:30
5770	92258j261_10	740	45	17-SEP-1992	06:44:05
5770	92258j261_10	2	65	17-SEP-1992	09:47:15
5771	92261j262_10	830	65	17-SEP-1992	10:02:55
5772	92261j262_10	34	65	17-SEP-1992	13:13:05
5778	92261j262_10	59	65	18-SEP-1992	11:44:45
5779	92262j266_2	872	65	18-SEP-1992	11:54:35
5780	92262j266_2	36	65	18-SEP-1992	15:09:05
5782	92262j266_2	60	45	19-SEP-1992	00:42:35
5783	92262j266_2	879	45	19-SEP-1992	00:52:35
5784	92262j266_2	288	45	19-SEP-1992	04:07:05
5785	92262j266_2	474	45	19-SEP-1992	07:21:35
5785	92262j266_2	236	65	19-SEP-1992	09:43:45
5786	92262j266_2	879	65	19-SEP-1992	10:36:05
5787	92262j266_2	846	65	19-SEP-1992	13:50:35
5789	92262j266_2	570	15	19-SEP-1992	21:00:35
5789	92262j266_2	261	45	19-SEP-1992	22:37:05
5790	92262j266_2	866	45	19-SEP-1992	23:34:05
5791	92262j266_2	866	45	20-SEP-1992	02:48:35
5792	92262j266_2	862	45	20-SEP-1992	06:03:05
5793	92262j266_2	837	65	20-SEP-1992	09:58:35
5794	92262j266_2	874	65	20-SEP-1992	12:32:05
5795	92262j266_2	613	15	20-SEP-1992	17:06:05
5795	92262j266_2	265	65	20-SEP-1992	15:46:35
5796	92262j266_2	881	15	20-SEP-1992	19:01:05
5797	92262j266_2	37	15	20-SEP-1992	22:15:35
5797	92262j266_2	775	45	20-SEP-1992	22:56:35
5799	92262j266_2	2068	45	21-SEP-1992	05:44:45
5800	92262j266_2	495	45	21-SEP-1992	07:59:05
5800	92262j266_2	863	65	21-SEP-1992	09:48:09
5801	92262j266_2	1858	65	21-SEP-1992	11:13:35
5802	92262j266_2	1771	65	21-SEP-1992	14:28:05
5804	92262j266_2	937	45	21-SEP-1992	22:39:23
5805	92262j266_2	1603	45	22-SEP-1992	00:12:30
5806	92262j266_2	1907	45	22-SEP-1992	03:26:30
5807	92262j266_2	1856	45	22-SEP-1992	06:41:30
5811	92265j272_2	1927	15	22-SEP-1992	20:26:30
5812	92265j272_2	1876	15	22-SEP-1992	22:53:30
5815	92265j272_2	1644	65	23-SEP-1992	09:52:23
5816	92265j272_2	1936	65	23-SEP-1992	11:51:30
5817	92265j272_2	78	15	23-SEP-1992	17:18:30
5817	92265j272_2	1005	65	23-SEP-1992	15:06:30
5818	92265j272_2	1630	15	23-SEP-1992	18:20:30
5819	92265j272_2	1661	15	23-SEP-1992	21:35:30
5820	92265j272_2	6	15	24-SEP-1992	00:49:30
5820	92265j272_2	581	45	24-SEP-1992	02:38:37
5821	92265j272_2	1939	45	24-SEP-1992	04:04:30
5822	92265j272_2	1568	45	24-SEP-1992	07:18:30
5822	92265j272_2	18	65	24-SEP-1992	10:00:30
5823	92265j272_2	1799	65	24-SEP-1992	10:33:30
5824	92265j272_2	1914	65	24-SEP-1992	13:47:30
5825	92265j272_2	1893	15	24-SEP-1992	17:48:30
5825	92265j272_2	8	65	24-SEP-1992	17:02:30
5826	92265j272_2	1822	15	24-SEP-1992	20:16:30
5826	92265j272_2	108	45	24-SEP-1992	22:27:43
5827	92265j272_2	1888	45	24-SEP-1992	23:31:30
5828	92265j272_2	1902	45	25-SEP-1992	02:45:30
5829	92265j272_2	1903	45	25-SEP-1992	05:59:30
5830	92265j272_2	2	45	25-SEP-1992	09:14:30
5831	92265j272_2	1906	65	25-SEP-1992	13:21:35
5833	92265j272_2	686	15	25-SEP-1992	20:14:08
5834	92265j272_2	802	15	25-SEP-1992	22:50:30
5835	92265j272_2	1240	45	26-SEP-1992	02:09:30
5836	92265j272_2	834	45	26-SEP-1992	05:19:30
5837	92265j272_2	188	45	26-SEP-1992	08:34:30
5837	92265j272_2	72	65	26-SEP-1992	10:29:30
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5839	92265j272_2	843	65	26-SEP-1992	15:03:30
5840	92265j272_2	1001	15	26-SEP-1992	18:17:30
5841	92265j272_2	858	15	26-SEP-1992	21:32:30
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5843	92265j272_2	842	45	27-SEP-1992	04:01:30
5844	92265j272_2	770	45	27-SEP-1992	07:15:30
5845	92265j272_2	935	65	27-SEP-1992	10:32:47
5846	92265j272_2	840	65	27-SEP-1992	13:44:30
5847	92265j272_2	814	15	27-SEP-1992	17:24:30
5848	92265j272_2	840	15	27-SEP-1992	20:13:30
5849	92265j272_2	70	15	27-SEP-1992	23:27:30
5851	92265j279_2	816	45	28-SEP-1992	06:20:30
5852	92272j279_2	7	45	28-SEP-1992	09:11:30
5855	92272j279_2	997	15	28-SEP-1992	17:32:30
5856	92272j279_2	816	15	28-SEP-1992	22:09:30
5857	92272j279_2	21	15	29-SEP-1992	01:23:30
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5860	92272j279_2	842	65	29-SEP-1992	11:07:30
5861	92272j279_2	761	65	29-SEP-1992	14:21:30
5862	92272j279_2	148	65	29-SEP-1992	17:36:30
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5870	92272j279_2	1907	15	30-SEP-1992	19:31:30
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5877	92272j279_2	2277	15	1-OCT-1992	18:27:21
5878	92272j279_2	2299	15	1-OCT-1992	21:27:30
5879	92272j279_2	1389	15	2-OCT-1992	01:04:05
5879	92272j279_2	540	45	2-OCT-1992	02:02:57
5880	92272j279_2	2300	45	2-OCT-1992	03:54:45
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5882	92272j279_2	2304	65	2-OCT-1992	10:23:45
5883	92272j279_2	2219	65	2-OCT-1992	13:38:15
5884	92272j279_2	1750	15	2-OCT-1992	17:31:43
5885	92272j279_2	2108	15	2-OCT-1992	20:07:15
5886	92272j279_2	12	45	3-OCT-1992	01:54:35
5887	92272j279_2	2296	45	3-OCT-1992	02:36:15
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14645 94255j262_2   689 65 17-SEP-1994 13:59:33
14650 94255j262_2  2020 15 17-SEP-1994 22:07:39
14651 94255j262_2   696 15 17-SEP-1994 23:15:15
14660 94255j262_2  1971 65 18-SEP-1994 13:34:51
14661 94255j262_2   681 65 18-SEP-1994 14:41:23
14666 94255j262_2  1791 15 18-SEP-1994 22:57:23
14667 94255j262_2   696 15 18-SEP-1994 23:57:03
14674 94262j269_2  1770 65 19-SEP-1994 11:18:33
14675 94262j269_2   759 65 19-SEP-1994 12:17:31
14680 94262j269_2  1960 15 19-SEP-1994 20:27:51
14681 94262j269_2   692 15 19-SEP-1994 21:33:11
14690 94262j269_2  1995 65 20-SEP-1994 11:52:47
14691 94262j269_2   688 65 20-SEP-1994 12:59:15
14696 94262j269_2  1738 15 20-SEP-1994 21:16:59
14697 94262j269_2   696 15 20-SEP-1994 22:14:53
14706 94262j269_2  1975 65 21-SEP-1994 12:35:09
14707 94262j269_2   693 65 21-SEP-1994 13:40:57
14712 94262j269_2  1974 15 21-SEP-1994 21:49:51
14713 94262j269_2   702 15 21-SEP-1994 22:56:35
14722 94262j269_2  1924 65 22-SEP-1994 13:18:31
14723 94262j269_2   705 65 22-SEP-1994 14:22:39
14728 94262j269_2  1844 15 22-SEP-1994 22:36:49
14729 94262j269_2   675 15 22-SEP-1994 23:38:15
14738 94262j269_2  2039 65 23-SEP-1994 13:56:21
14739 94262j269_2   676 65 23-SEP-1994 15:04:17
14742 94262j269_2  2023 15 23-SEP-1994 20:07:17
14743 94262j269_2   691 15 23-SEP-1994 21:14:43
14758 94262j269_2  2050 15 24-SEP-1994 20:47:45
14759 94262j269_2   668 15 24-SEP-1994 21:56:21
14768 94262j269_2  2051 65 25-SEP-1994 12:13:59
14769 94262j269_2   668 65 25-SEP-1994 13:22:21
14774 94262j269_2  2043 15 25-SEP-1994 21:29:51
14784 94269j276_2  1858 65 26-SEP-1994 12:56:15
14785 94269j276_2   417 65 26-SEP-1994 14:12:33
14790 94269j276_2  1860 15 26-SEP-1994 22:10:59
14791 94269j276_2   344 15 26-SEP-1994 23:28:33
14800 94269j276_2  1856 65 27-SEP-1994 13:36:49
14801 94269j276_2   365 65 27-SEP-1994 14:55:11
14804 94269j276_2  1757 15 27-SEP-1994 19:50:17
14805 94269j276_2   375 15 27-SEP-1994 21:05:47
14814 94269j276_2  1766 65 28-SEP-1994 11:15:03
14815 94269j276_2    80 65 28-SEP-1994 12:32:33
14820 94269j276_2  1895 15 28-SEP-1994 20:25:47
14821 94269j276_2   197 15 28-SEP-1994 21:47:41
14832 94269j276_2  1867 65 29-SEP-1994 14:54:59
14833 94269j276_2   189 65 29-SEP-1994 16:16:47
14836 94269j276_2  1719 15 29-SEP-1994 21:08:59
14837 94269j276_2   168 15 29-SEP-1994 22:26:27
14846 94269j276_2  1948 65 30-SEP-1994 12:25:13
14852 94269j276_2  1936 15 30-SEP-1994 21:39:55
14853 94269j276_2   126 15 30-SEP-1994 23:05:45
14862 94269j276_2  2018 65  1-OCT-1994 13:05:07
14863 94269j276_2    41 65  1-OCT-1994 14:28:07
14866 94269j276_2  1885 15  1-OCT-1994 19:13:57
14867 94269j276_2   172 15  1-OCT-1994 20:38:59
14878 94269j276_2  1885 65  2-OCT-1994 13:42:19
14882 94269j276_2  1975 15  2-OCT-1994 19:53:41
14892 94276j283_2  1918 65  3-OCT-1994 11:14:09
14898 94276j283_2  1848 15  3-OCT-1994 20:30:29
14908 94276j283_2  1889 65  4-OCT-1994 11:52:25
14914 94276j283_2  1772 15  4-OCT-1994 21:10:39
14915 94276j283_2   112 15  4-OCT-1994 22:33:45
14926 94276j283_2  1774 65  5-OCT-1994 15:38:19
14927 94276j283_2    89 65  5-OCT-1994 17:02:29
14930 94276j283_2  1656 15  5-OCT-1994 21:51:57
14940 94276j283_2  1442 65  6-OCT-1994 13:22:15
14941 94276j283_2   108 65  6-OCT-1994 14:35:39
14944 94276j283_2  1978 15  6-OCT-1994 19:19:45
14956 94276j283_2  1400 65  7-OCT-1994 13:48:45
14957 94276j283_2    85 65  7-OCT-1994 15:13:27
14960 94276j283_2  1860 15  7-OCT-1994 19:55:39
14961 94276j283_2    87 15  7-OCT-1994 21:23:29
14970 94276j283_2  1694 65  8-OCT-1994 11:24:07
14971 94276j283_2    93 65  8-OCT-1994 12:46:33
14976 94276j283_2  1997 15  8-OCT-1994 20:33:51
14986 94276j283_2  1712 65  9-OCT-1994 11:58:15
14992 94276j283_2  1814 15  9-OCT-1994 21:11:53
```

Appendix F

PVO and Magellan Data Arcs

The following information is included in this appendix:

1. Start and stop times for each data arc for PVO low altitude.
2. Start and stop times for each data arc for PVO high altitude.
3. PVO maneuvers.
3. Start and stop times for each data arc for Magellan cycle4.
4. Start and stop times for each data arc for Magellan cycle5.
5. Hide information for Magellan cycle 4.
6. Hide information for Magellan cycles 5 and 6.

PVO low altitude data arcs:

09-DEC-78 10:00	11-DEC-78 04:00
11-DEC-78 06:00	13-DEC-78 04:00
16-DEC-78 01:00	20-DEC-78 00:00
20-DEC-78 07:00	22-DEC-78 22:00
23-DEC-78 01:00	27-DEC-78 23:00
28-DEC-78 04:00	03-JAN-79 05:00
11-JAN-79 10:00	16-JAN-79 09:59
17-JAN-79 12:00	24-JAN-79 07:00
24-JAN-79 13:00	31-JAN-79 07:00
31-JAN-79 11:00	02-FEB-79 00:00
02-FEB-79 03:00	07-FEB-79 07:00
07-FEB-79 11:00	13-FEB-79 20:00
14-FEB-79 11:00	17-FEB-79 00:00
17-FEB-79 05:00	21-FEB-79 04:59
22-FEB-79 23:00	27-FEB-79 06:00
27-FEB-79 11:00	03-MAR-79 00:00
03-MAR-79 04:00	08-MAR-79 04:00
08-MAR-79 04:00	13-MAR-79 12:00
14-MAR-79 01:00	18-MAR-79 00:59
18-MAR-79 01:00	22-MAR-79 23:00
23-MAR-79 00:00	28-MAR-79 23:59
29-MAR-79 00:00	03-APR-79 23:30
04-APR-79 02:00	10-APR-79 01:59
10-APR-79 02:00	15-APR-79 01:59
15-APR-79 02:00	19-APR-79 01:59
19-APR-79 02:00	24-APR-79 01:59
25-APR-79 12:00	30-APR-79 02:00
30-APR-79 13:00	08-MAY-79 06:00
11-MAY-79 03:00	16-MAY-79 07:00
16-MAY-79 10:00	24-MAY-79 07:00
24-MAY-79 12:00	28-MAY-79 07:00
29-MAY-79 10:00	31-MAY-79 17:00
01-JUN-79 02:00	06-JUN-79 06:00
06-JUN-79 10:00	14-JUN-79 07:00
14-JUN-79 12:00	22-JUN-79 07:00
22-JUN-79 12:00	26-JUN-79 00:00
26-JUN-79 04:00	01-JUL-79 03:59
01-JUL-79 04:00	06-JUL-79 17:00
06-JUL-79 17:30	11-JUL-79 17:00
19-DEC-79 04:00	21-DEC-79 22:00
21-DEC-79 22:00	27-DEC-79 12:00
27-DEC-79 22:00	03-JAN-80 10:00
03-JAN-80 22:00	08-JAN-80 10:00
09-JAN-80 09:00	15-JAN-80 04:00
15-JAN-80 22:00	22-JAN-80 12:00
23-JAN-80 00:00	29-JAN-80 12:00
29-JAN-80 23:00	05-FEB-80 18:45
06-FEB-80 09:00	07-FEB-80 19:00
08-FEB-80 08:00	13-FEB-80 07:59
13-FEB-80 08:00	18-FEB-80 17:59
18-FEB-80 18:00	23-FEB-80 17:59
23-FEB-80 18:00	28-FEB-80 12:00
28-FEB-80 20:00	07-MAR-80 19:59
07-MAR-80 20:00	14-MAR-80 14:00
14-MAR-80 21:30	19-MAR-80 21:29
19-MAR-80 21:30	23-MAR-80 21:29
23-MAR-80 21:30	28-MAR-80 21:29
28-MAR-80 21:30	01-APR-80 16:00
01-APR-80 22:50	08-APR-80 00:00
09-APR-80 15:00	15-APR-80 22:00
19-APR-80 17:00	22-APR-80 15:00
22-APR-80 22:45	29-APR-80 03:00
30-APR-80 00:00	05-MAY-80 23:59
07-MAY-80 00:00	13-MAY-80 14:00
14-MAY-80 10:00	20-MAY-80 02:00
21-MAY-80 11:00	25-MAY-80 21:00
25-MAY-80 21:00	30-MAY-80 20:59
30-MAY-80 21:00	03-JUN-80 20:59
03-JUN-80 22:00	08-JUN-80 21:59
08-JUN-80 22:00	12-JUN-80 20:00
12-JUN-80 20:25	19-JUN-80 08:00
19-JUN-80 21:55	26-JUN-80 07:59
26-JUN-80 20:10	03-JUL-80 20:09
03-JUL-80 21:00	10-JUL-80 02:00
10-JUL-80 21:00	13-JUL-80 09:00
13-JUL-80 22:00	21-JUL-80 21:59
21-JUL-80 22:00	28-JUL-80 10:00
31-JUL-80 00:00	09-AUG-80 10:00
09-AUG-80 10:00	17-AUG-80 00:00
17-AUG-80 00:00	26-AUG-80 23:59
27-AUG-80 00:00	05-SEP-80 23:59
06-SEP-80 00:00	15-SEP-80 23:59
16-SEP-80 00:00	23-SEP-80 10:00
25-SEP-80 01:00	05-OCT-80 00:59
05-OCT-80 01:00	15-OCT-80 00:59
15-OCT-80 01:00	25-OCT-80 00:59
25-OCT-80 01:00	04-NOV-80 00:59
04-NOV-80 01:00	14-NOV-80 00:59
14-NOV-80 01:00	23-NOV-80 00:00
23-NOV-80 01:00	04-DEC-80 00:00

PVO high altitude data arcs:

```
06-NOV-81 13:49  09-NOV-81 06:00
12-NOV-81 05:00  16-NOV-81 06:00
19-NOV-81 23:00  23-NOV-81 06:00
26-NOV-81 23:00  30-NOV-81 06:00
02-DEC-81 13:51  09-DEC-81 10:00
09-DEC-81 10:01  15-DEC-81 10:00
15-DEC-81 10:01  22-DEC-81 10:00
22-DEC-81 10:00  29-DEC-81 02:00
29-DEC-81 10:01  05-JAN-82 10:00
05-JAN-82 10:01  12-JAN-82 10:00
12-JAN-82 10:00  20-JAN-82 05:00
20-JAN-82 10:00  23-JAN-82 06:00
24-JAN-82 23:00  29-JAN-82 06:00
30-JAN-82 23:00  03-FEB-82 05:00
03-FEB-82 10:00  05-FEB-82 06:00
06-FEB-82 23:00  10-FEB-82 06:00
13-FEB-82 23:00  17-FEB-82 06:00
20-FEB-82 23:00  24-FEB-82 06:00
27-FEB-82 23:00  02-MAR-82 05:00
02-MAR-82 10:00  04-MAR-82 06:00
06-MAR-82 23:00  10-MAR-82 06:00
13-MAR-82 23:00  17-MAR-82 06:00
20-MAR-82 23:00  23-MAR-82 22:50
27-MAR-82 23:00  30-MAR-82 22:50
03-APR-82 23:00  06-APR-82 05:00
06-APR-82 10:00  09-APR-82 06:00
10-APR-82 23:00  13-APR-82 22:50
17-APR-82 23:00  20-APR-82 22:50
24-APR-82 23:00  27-APR-82 22:50
01-MAY-82 23:00  04-MAY-82 22:50
08-MAY-82 23:00  11-MAY-82 22:50
15-MAY-82 23:00  18-MAY-82 22:50
22-MAY-82 23:00  25-MAY-82 22:50
29-MAY-82 23:00  01-JUN-82 22:50
05-JUN-82 23:30  08-JUN-82 23:29
12-JUN-82 23:30  15-JUN-82 23:00
19-JUN-82 23:30  22-JUN-82 23:00
26-JUN-82 23:30  29-JUN-82 23:00
03-JUL-82 23:30  06-JUL-82 23:00
10-JUL-82 23:30  13-JUL-82 23:00
17-JUL-82 23:30  20-JUL-82 23:00
24-JUL-82 23:30  27-JUL-82 23:00
31-JUL-82 23:30  03-AUG-82 23:00
07-AUG-82 23:30  10-AUG-82 05:00
14-AUG-82 23:30  17-AUG-82 23:00
20-AUG-82 23:30  24-AUG-82 23:00
28-AUG-82 23:30  31-AUG-82 23:00
04-SEP-82 23:30  07-SEP-82 23:00
```

PVO maneuvers:

78/341/0536	DEC 07	m	alt. 200 km/ period trim
341/0630	DEC 07	m	reor.
342/0411	DEC 08	m	alt. 180 km
345/0436	DEC 11	m	alt. 170 km
347/0451	DEC 13	m	alt. 160 km
347/1541	DEC 13	m	period trim
349/0536	DEC 15	m	spin trim/alt. 155 km
354/0103	DEC 20	m	reor.
354/0537	DEC 20	m	alt. 150 km
356/2343	DEC 22	m	reor.
362/0040	DEC 28	m	reor. star map
362/0240	DEC 28	m	reor. start Per. Eclipse #1
79/003/0736	JAN 03	m	alt. 148 km
003/2145	JAN 03	m	period trim/spin trim
011/0851	JAN 11	m	alt. 150 km/spin trim
017/1026	JAN 17	m	alt. 147 km/spin trim
024/0943	JAN 24	m	alt. 145 km/spin trim
024/1113	JAN 24	m	reor.
031/0928	JAN 31	m	alt. 142 km/spin trim
033/0107	FEB 02	m	reor.
038/0947	FEB 07	m	spin trim/alt. 142 km
045/0932	FEB 14	m	spin trim/alt. 142 km
048/0135	FEB 17	m	reor.
052/0930	FEB 21	m	spin trim/alt. 142 km
058/0855	FEB 27	m	spin trim/alt. 142 km
062/0134	MAR 03	m	reor.
072/1904	MAR 13	m	period trim/spin trim
073/0037	MAR 14	m	reor.
081 2328	MAR 22	m	reor.
094/0058	APR 04	m	reor./spin trim
115/0945	APR 25	m	reor.
115/1145	APR 25	m	alt. 148 km/spin trim
120/1125	APR 30	m	alt. 148 km/spin trim
128/0930	MAY 08	m	reor./alt. reduct./spin trim
136/0900	MAY 16	m	spin trim/alt. reduction
144/1030	MAY 24	m	spin trim/reor./alt. reduct.
149/1000	MAY 29	m	reor./spin trim/alt. reduct.
151/2020	MAY 31	m	period trim/spin trim
157/0830	JUN 06	m	reor./spin trim/alt. reduct.
165/1130	JUN 14	m	reor./spin trim/alt. reduct.
173/1120	JUN 22	m	reor./spin trim/alt. reduct.
177/0327	JUN 26	m	reor.
187/1740	JUL 06	m	reor.
194/0325	JUL 13	m	reor.
205/2220	JUL 24	m	period trim
206/0425	JUL 25	m	spin trim/reor.
216/0632	AUG 04	m	reor.
255/0430	SEP 12	m	reor./spin trim/alt. reduct.
256/2254	SEP 13	m	spin trim
258/0455	SEP 15	m	reor.
260/2312	SEP 17	m	period trim/spin trim
262/0350	SEP 19	m	reor./spin trim/alt. reduct.
269/0440	SEP 26	m	reor./spin trim/alt. reduct.
276/0550	OCT 03	m	reor.
277/0134	OCT 04	m	spin trim/alt. reduction
283/1354	OCT 10	m	reor.

284/0223	OCT 11	m	spin trim/alt. reduction
292/1650	OCT 19	m	reor.
305/1705	NOV 01	m	reor.
318/2001	NOV 14	m	reor.
324/1957	NOV 20	m	reor.
338/1948	DEC 04	m	reor./spin trim
345/2123	DEC 11	m	alt. reduction/spin trim
352/2120	DEC 18	m	alt. reduction/spin trim
362/0016	DEC 28	m	reor.
362/0744	DEC 28	m	alt. reduction/spin trim
80/003/2116	JAN 03	m	alt. reduct./spin trim/reor.
008/2106	JAN 08	m	alt. reduction/spin trim
009/0659	JAN 09	m	period trim/spin trim
015/2200	JAN 15	m	spin trim/alt. reduction
022/2200	JAN 22	m	reor./spin trim/alt. reduct.
029 2215	JAN 29	m	reor.
030/0815	JAN 30	m	alt. reduction/spin trim
037/0830	FEB 06	m	period trim
038/1950	FEB 07	m	reor.
039/0818	FEB 08	m	spin trim
059/2215	FEB 28	m	reor.
074/2345	MAR 14	m	reor./spin trim
093/0150	APR 02	m	reor./alt. reduct./spin trim
101/0035	APR 10	m	spin trim/alt. reduction
107/0100	APR 16	m	alt. reduct./spin trim/reor.
114/0050	APR 23	m	spin trim/alt. reduction
121/0030	APR 30	m	reor./spin trim/alt. reduct.
128/1007	MAY 07	m	spin trim/alt. reduction
134/2330	MAY 13	m	reor./spin trim/alt. reduct.
135/0932	MAY 14	m	period trim/spin trim
141/0930	MAY 20	m	reor./spin trim/alt. reduct.
142/0940	MAY 21	m	period trim/spin trim
155/2120	JUN 03	m	reor. (special)
164/2100	JUN 12	m	reor.
171/2230	JUN 19	m	reor.
179/0130	JUN 27	m	reor./spin trim
192/1428	JUL 10	m	spin trim 6 sec
195/1440	JUL 13	m	spin trim 12 sec
210/2300	JUL 28	m	reor./spin trim
269/1813	SEP 25	m	spin trim
328/0115	NOV 23	m	reor.
346/1722	DEC 11	m	reor.
81/006/0310	JAN 06	m	reor.
036/0450	FEB 05	m	period trim
036/1142	FEB 05	m	reor./spin trim
037/0315	FEB 06	m	period trim
037 1920	FEB 06	m	reor./spin trim
057/0500	FEB 26	m	reor.
076/0700	MAR 17	m	spin trim/reor.
114/0100	APR 24	m	reor.
127/0207	MAY 07	m	period trim
127/2215	MAY 07	m	reor.
141/0208	MAY 21	m	spin trim
142/0208	MAY 22	m	spin trim
148/0207	MAY 28	m	reor.
168/0630	JUN 17	m	reor./spin trim
203/0715	JUL 22	m	reor./spin trim (error)
204/0745	JUL 23	m	reor./spin trim (correct)

238/2015	AUG 26	m	reor./spin trim
268/0830	SEP 25	m	reor./spin trim
336/0152	DEC 02	m	spin trim
363/0820	DEC 29	m	reor./spin trim
82/020/0630	JAN 20	m	reor.
034/0645	FEB 03	m	reor./spin trim
061/0740	MAR 02	m	reor.
097/0144	APR 07	m	spin trim
133/0730	MAY 13	m	spin trim/reor.
176/0720	JUN 25	m	spin trim/reor.
222/0700	AUG 10	m	reor.
252/0620	SEP 09	m	reor.
296/0125	OCT 23	m	reor.
325/0630	NOV 21	m	reor.
343/0615	DEC 09	m	reor.

Cycle 4 data arcs:

15-SEP-92 03:00	15-SEP-92 22:25
15-SEP-92 22:45	17-SEP-92 03:30
17-SEP-92 03:50	18-SEP-92 11:40
18-SEP-92 12:00	19-SEP-92 20:10
19-SEP-92 20:30	20-SEP-92 18:45
20-SEP-92 19:00	21-SEP-92 20:50
21-SEP-92 21:10	22-SEP-92 19:40
22-SEP-92 20:00	23-SEP-92 18:45
23-SEP-92 19:00	24-SEP-92 17:15
24-SEP-92 17:30	25-SEP-92 22:00
25-SEP-92 22:15	27-SEP-92 03:15
27-SEP-92 03:30	28-SEP-92 18:00
28-SEP-92 18:25	30-SEP-92 02:40
30-SEP-92 03:00	01-OCT-92 17:25
01-OCT-92 17:45	02-OCT-92 19:40
02-OCT-92 19:45	03-OCT-92 18:15
03-OCT-92 18:15	05-OCT-92 01:10
05-OCT-92 01:30	06-OCT-92 01:15
06-OCT-92 01:40	06-OCT-92 23:45
07-OCT-92 00:10	08-OCT-92 02:00
08-OCT-92 02:15	09-OCT-92 10:25
09-OCT-92 10:45	11-OCT-92 01:50
11-OCT-92 02:00	12-OCT-92 19:20
12-OCT-92 19:20	13-OCT-92 18:30
13-OCT-92 18:50	14-OCT-92 17:30
14-OCT-92 17:45	15-OCT-92 22:00
15-OCT-92 22:25	17-OCT-92 00:00
17-OCT-92 00:30	18-OCT-92 11:50
18-OCT-92 12:05	19-OCT-92 10:30
19-OCT-92 10:45	20-OCT-92 18:50
20-OCT-92 19:10	21-OCT-92 17:30
21-OCT-92 17:55	23-OCT-92 02:00
23-OCT-92 02:15	24-OCT-92 19:50
24-OCT-92 20:05	26-OCT-92 01:10
26-OCT-92 01:25	27-OCT-92 06:20
27-OCT-92 06:40	29-OCT-92 00:30
29-OCT-92 00:50	30-OCT-92 21:50
30-OCT-92 22:10	31-OCT-92 16:45
31-OCT-92 17:40	02-NOV-92 11:25
02-NOV-92 11:45	04-NOV-92 05:35
04-NOV-92 05:55	05-NOV-92 20:20
05-NOV-92 20:40	07-NOV-92 16:00
07-NOV-92 18:00	08-NOV-92 19:50
08-NOV-92 20:10	10-NOV-92 07:20
10-NOV-92 07:40	11-NOV-92 19:05
11-NOV-92 19:25	13-NOV-92 00:10
13-NOV-92 00:30	14-NOV-92 11:50
14-NOV-92 12:10	16-NOV-92 11:10
16-NOV-92 12:45	17-NOV-92 07:45
17-NOV-92 08:10	18-NOV-92 16:20
18-NOV-92 16:40	19-NOV-92 21:20
19-NOV-92 21:40	21-NOV-92 15:30
21-NOV-92 15:55	23-NOV-92 00:00
23-NOV-92 00:15	24-NOV-92 23:20
25-NOV-92 00:55	26-NOV-92 15:20
26-NOV-92 15:45	27-NOV-92 14:00
27-NOV-92 14:25	28-NOV-92 19:20
28-NOV-92 19:40	30-NOV-92 13:20
30-NOV-92 13:40	01-DEC-92 18:35
01-DEC-92 18:55	03-DEC-92 18:00
03-DEC-92 22:40	04-DEC-92 21:00
04-DEC-92 21:25	06-DEC-92 02:20
06-DEC-92 02:40	07-DEC-92 07:20
07-DEC-92 07:40	08-DEC-92 12:25
08-DEC-92 12:45	09-DEC-92 14:20
09-DEC-92 14:45	10-DEC-92 19:35
10-DEC-92 19:55	12-DEC-92 00:40
12-DEC-92 01:00	12-DEC-92 23:20
12-DEC-92 23:40	14-DEC-92 14:10
14-DEC-92 14:30	15-DEC-92 12:50
15-DEC-92 13:10	17-DEC-92 00:30
17-DEC-92 00:55	17-DEC-92 23:10
17-DEC-92 23:30	19-DEC-92 01:00
19-DEC-92 01:25	19-DEC-92 23:50
20-DEC-92 00:10	21-DEC-92 11:20
21-DEC-92 11:45	23-DEC-92 05:00
23-DEC-92 15:30	25-DEC-92 03:00
26-DEC-92 01:55	27-DEC-92 00:10
27-DEC-92 00:30	27-DEC-92 23:00
27-DEC-92 23:15	29-DEC-92 00:50
29-DEC-92 01:10	31-DEC-92 00:00
01-JAN-93 00:15	02-JAN-93 21:10
02-JAN-93 21:30	03-JAN-93 23:10
03-JAN-93 23:30	05-JAN-93 01:10
05-JAN-93 01:25	06-JAN-93 16:00
06-JAN-93 16:15	07-JAN-93 21:10
07-JAN-93 21:30	08-JAN-93 23:10
08-JAN-93 23:25	09-JAN-93 18:20
09-JAN-93 18:45	11-JAN-93 12:20
11-JAN-93 12:45	12-JAN-93 14:15
12-JAN-93 14:45	14-JAN-93 04:20
14-JAN-93 15:15	15-JAN-93 17:00
15-JAN-93 17:15	16-JAN-93 19:00
16-JAN-93 19:15	17-JAN-93 17:30
17-JAN-93 17:45	19-JAN-93 01:00
19-JAN-93 02:15	20-JAN-93 03:40
20-JAN-93 04:00	21-JAN-93 12:10
21-JAN-93 12:30	22-JAN-93 20:40
22-JAN-93 21:00	23-JAN-93 18:15
23-JAN-93 19:30	24-JAN-93 14:30
24-JAN-93 15:00	25-JAN-93 20:00
25-JAN-93 20:15	27-JAN-93 01:00
27-JAN-93 01:15	27-JAN-93 17:15
27-JAN-93 17:30	28-JAN-93 22:10
28-JAN-93 22:30	29-JAN-93 16:45
29-JAN-93 18:00	30-JAN-93 19:40
30-JAN-93 20:00	31-JAN-93 21:25
31-JAN-93 21:45	01-FEB-93 20:10
01-FEB-93 20:30	02-FEB-93 22:10
02-FEB-93 22:30	03-FEB-93 20:40
03-FEB-93 21:00	04-FEB-93 16:10
04-FEB-93 16:30	05-FEB-93 18:10
05-FEB-93 18:30	06-FEB-93 16:40
06-FEB-93 17:00	07-FEB-93 18:40

07-FEB-93 19:00	08-FEB-93 17:10
08-FEB-93 17:45	09-FEB-93 19:10
09-FEB-93 19:30	10-FEB-93 21:00
10-FEB-93 21:30	11-FEB-93 20:00
11-FEB-93 20:15	13-FEB-93 04:15
13-FEB-93 04:30	14-FEB-93 02:00
14-FEB-93 03:15	15-FEB-93 17:20
15-FEB-93 18:00	16-FEB-93 23:00
16-FEB-93 23:15	17-FEB-93 11:45
17-FEB-93 12:00	18-FEB-93 13:30
18-FEB-93 14:00	19-FEB-93 12:20
19-FEB-93 12:45	20-FEB-93 13:30
20-FEB-93 14:30	21-FEB-93 13:00
21-FEB-93 13:15	22-FEB-93 11:30
22-FEB-93 12:00	23-FEB-93 16:30
23-FEB-93 17:00	24-FEB-93 08:00
24-FEB-93 09:15	25-FEB-93 11:00
25-FEB-93 11:15	26-FEB-93 12:30
26-FEB-93 13:00	27-FEB-93 18:00
27-FEB-93 18:15	28-FEB-93 13:15
28-FEB-93 13:45	01-MAR-93 11:45
01-MAR-93 12:15	02-MAR-93 09:45
02-MAR-93 11:00	03-MAR-93 12:30
03-MAR-93 13:00	04-MAR-93 11:00
04-MAR-93 11:30	05-MAR-93 16:15
05-MAR-93 16:45	06-MAR-93 11:30
06-MAR-93 12:00	07-MAR-93 12:45
07-MAR-93 14:00	08-MAR-93 11:45
08-MAR-93 12:45	09-MAR-93 14:15
09-MAR-93 14:30	11-MAR-93 05:15
11-MAR-93 05:30	12-MAR-93 16:15
12-MAR-93 17:00	13-MAR-93 15:20
13-MAR-93 15:45	15-MAR-93 09:20
15-MAR-93 09:45	17-MAR-93 00:15
17-MAR-93 00:45	17-MAR-93 16:20
17-MAR-93 17:00	18-MAR-93 18:15
18-MAR-93 18:45	20-MAR-93 16:00
20-MAR-93 16:15	22-MAR-93 00:10
22-MAR-93 00:30	23-MAR-93 08:40
23-MAR-93 09:00	24-MAR-93 13:15
24-MAR-93 14:00	25-MAR-93 15:40
25-MAR-93 16:00	27-MAR-93 03:10
27-MAR-93 03:30	28-MAR-93 14:45
28-MAR-93 15:15	29-MAR-93 13:15
29-MAR-93 13:45	31-MAR-93 04:30
31-MAR-93 04:45	01-APR-93 12:45
01-APR-93 13:00	02-APR-93 14:40
02-APR-93 15:00	03-APR-93 13:15
03-APR-93 13:45	04-APR-93 15:10
04-APR-93 15:30	05-APR-93 14:00
05-APR-93 14:15	06-APR-93 12:20
06-APR-93 12:45	07-APR-93 14:30
07-APR-93 14:45	08-APR-93 13:15
08-APR-93 13:30	09-APR-93 21:30
09-APR-93 21:45	10-APR-93 13:40
10-APR-93 14:00	11-APR-93 12:30
11-APR-93 12:45	12-APR-93 07:30
12-APR-93 08:00	13-APR-93 13:00
13-APR-93 13:15	14-APR-93 07:30
14-APR-93 08:45	15-APR-93 10:10
15-APR-93 10:30	16-APR-93 05:40
16-APR-93 06:00	17-APR-93 07:45
17-APR-93 08:00	18-APR-93 09:15
18-APR-93 09:45	19-APR-93 08:00
19-APR-93 08:30	20-APR-93 10:00
20-APR-93 10:15	21-APR-93 18:20
21-APR-93 18:45	22-APR-93 14:00
22-APR-93 14:15	23-APR-93 14:45
23-APR-93 16:00	24-APR-93 16:45
24-APR-93 18:00	25-APR-93 18:30
25-APR-93 19:45	26-APR-93 17:15
26-APR-93 18:30	27-APR-93 20:00
27-APR-93 20:30	29-APR-93 07:40
29-APR-93 08:00	30-APR-93 19:15
30-APR-93 19:45	01-MAY-93 17:45
01-MAY-93 18:15	02-MAY-93 20:00
02-MAY-93 20:15	03-MAY-93 22:00
03-MAY-93 22:00	04-MAY-93 20:15
04-MAY-93 20:45	05-MAY-93 18:30
05-MAY-93 19:30	06-MAY-93 20:00
06-MAY-93 21:15	07-MAY-93 19:30
07-MAY-93 20:00	09-MAY-93 07:10
09-MAY-93 07:30	10-MAY-93 05:00
10-MAY-93 06:15	11-MAY-93 11:00
11-MAY-93 11:15	12-MAY-93 05:30
12-MAY-93 06:45	13-MAY-93 08:10
13-MAY-93 08:30	14-MAY-93 16:30
14-MAY-93 17:00	15-MAY-93 14:15
15-MAY-93 15:30	16-MAY-93 16:15
16-MAY-93 17:30	18-MAY-93 04:45
18-MAY-93 05:00	19-MAY-93 06:30
19-MAY-93 07:00	20-MAY-93 12:20
20-MAY-93 12:40	21-MAY-93 16:45
21-MAY-93 17:15	22-MAY-93 15:15
22-MAY-93 15:45	23-MAY-93 10:00
23-MAY-93 11:15	24-MAY-93 06:15
24-MAY-93 06:45	24-MAY-93 21:30

Cycle 5 and 6 data arcs:

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06-AUG-93 00:15  06-AUG-93 20:45
07-AUG-93 10:00  08-AUG-93 01:00
08-AUG-93 09:00  08-AUG-93 16:45
08-AUG-93 18:30  09-AUG-93 02:15
09-AUG-93 12:15  09-AUG-93 22:40
10-AUG-93 11:30  10-AUG-93 19:15
12-AUG-93 13:50  13-AUG-93 03:45
14-AUG-93 11:50  15-AUG-93 03:10
16-AUG-93 11:50  16-AUG-93 17:40
17-AUG-93 12:00  18-AUG-93 00:30
18-AUG-93 12:20  18-AUG-93 23:20
19-AUG-93 20:00  20-AUG-93 00:35
20-AUG-93 11:40  21-AUG-93 00:50
21-AUG-93 04:20  21-AUG-93 17:35
22-AUG-93 04:00  22-AUG-93 08:15
22-AUG-93 13:25  23-AUG-93 06:30
23-AUG-93 21:00  24-AUG-93 07:40
24-AUG-93 12:40  25-AUG-93 00:15
25-AUG-93 20:00  26-AUG-93 16:25
27-AUG-93 08:10  28-AUG-93 00:05
28-AUG-93 03:45  28-AUG-93 07:50
28-AUG-93 17:40  29-AUG-93 16:40
30-AUG-93 02:20  30-AUG-93 08:30
30-AUG-93 19:40  31-AUG-93 11:15
01-SEP-93 03:40  01-SEP-93 18:35
01-SEP-93 22:00  02-SEP-93 17:50
02-SEP-93 18:00  03-SEP-93 12:10
03-SEP-93 14:45  04-SEP-93 00:30
04-SEP-93 04:00  05-SEP-93 00:00
05-SEP-93 03:50  05-SEP-93 17:30
06-SEP-93 04:00  06-SEP-93 16:30
07-SEP-93 03:50  08-SEP-93 00:00
08-SEP-93 04:10  08-SEP-93 23:40
09-SEP-93 04:00  10-SEP-93 00:00
10-SEP-93 04:00  10-SEP-93 23:40
11-SEP-93 03:30  12-SEP-93 00:00
12-SEP-93 04:00  12-SEP-93 17:30
12-SEP-93 19:10  13-SEP-93 06:30
13-SEP-93 06:00  14-SEP-93 01:20
14-SEP-93 04:20  14-SEP-93 23:30
15-SEP-93 00:50  15-SEP-93 18:00
16-SEP-93 00:30  16-SEP-93 21:10
17-SEP-93 11:55  18-SEP-93 08:10
18-SEP-93 20:15  19-SEP-93 15:30
19-SEP-93 21:30  20-SEP-93 07:00
20-SEP-93 21:20  21-SEP-93 14:40
22-SEP-93 01:45  22-SEP-93 15:00
23-SEP-93 01:15  23-SEP-93 23:00
24-SEP-93 02:40  24-SEP-93 23:00
25-SEP-93 05:00  25-SEP-93 16:30
25-SEP-93 18:30  26-SEP-93 12:00
26-SEP-93 16:00  27-SEP-93 07:00
27-SEP-93 07:00  27-SEP-93 16:30
27-SEP-93 19:30  28-SEP-93 16:30
# Periapse raise maneuver
# Sept 28 17:18
28-SEP-93 19:30  29-SEP-93 16:30
29-SEP-93 19:30  30-SEP-93 16:00
01-OCT-93 05:00  01-OCT-93 22:00
02-OCT-93 04:00  02-OCT-93 22:30
03-OCT-93 00:45  03-OCT-93 16:30
03-OCT-93 19:30  04-OCT-93 07:00
04-OCT-93 07:00  04-OCT-93 17:45
04-OCT-93 19:40  05-OCT-93 16:10
05-OCT-93 20:45  06-OCT-93 12:45
# Bistatic radar Oct 6, 12h to 22h
07-OCT-93 01:15  08-OCT-93 00:00
08-OCT-93 00:45  08-OCT-93 22:15
09-OCT-93 05:25  10-OCT-93 03:10
10-OCT-93 05:30  10-OCT-93 16:00
10-OCT-93 19:00  11-OCT-93 07:00
11-OCT-93 07:00  11-OCT-93 22:00
12-OCT-93 06:00  12-OCT-93 23:50
13-OCT-93 02:30  13-OCT-93 16:05
14-OCT-93 02:00  14-OCT-93 22:20
15-OCT-93 01:10  15-OCT-93 22:50
16-OCT-93 01:25  16-OCT-93 22:50
17-OCT-93 01:00  17-OCT-93 13:40
17-OCT-93 15:10  18-OCT-93 07:00
18-OCT-93 19:45  19-OCT-93 16:50
20-OCT-93 01:00  20-OCT-93 15:40
21-OCT-93 02:50  21-OCT-93 21:35
22-OCT-93 13:30  23-OCT-93 07:45
23-OCT-93 13:30  24-OCT-93 08:00
24-OCT-93 13:25  25-OCT-93 07:00
# Began to lose lock 25-OCT 16:10
# Lost lock from 25-OCT 18:33
# to 26-OCT 01:00ish
# Medium gain antenna, S-Band only
26-OCT-93 03:30  26-OCT-93 15:15
26-OCT-93 16:00  27-OCT-93 04:50
27-OCT-93 12:00  28-OCT-93 06:20
28-OCT-93 13:30  28-OCT-93 23:00
# Return to high gain antenna
# 28-OCT 23:25
28-OCT-93 23:30  29-OCT-93 15:40
29-OCT-93 21:10  30-OCT-93 15:30
30-OCT-93 18:50  31-OCT-93 09:30
31-OCT-93 14:00  01-NOV-93 07:00
01-NOV-93 07:15  01-NOV-93 14:05
01-NOV-93 19:35  02-NOV-93 09:20
02-NOV-93 13:45  03-NOV-93 09:05
03-NOV-93 13:50  04-NOV-93 10:50
04-NOV-93 13:20  05-NOV-93 01:05
05-NOV-93 06:40  06-NOV-93 05:50
06-NOV-93 06:45  07-NOV-93 01:25
07-NOV-93 02:45  07-NOV-93 22:50
08-NOV-93 10:45  09-NOV-93 05:50
# Bistatic radar
# Nov 9, 8:35 to 11:44
09-NOV-93 13:35  10-NOV-93 03:30
10-NOV-93 10:05  11-NOV-93 00:20
11-NOV-93 00:25  11-NOV-93 15:40
11-NOV-93 20:20  12-NOV-93 17:40
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12-NOV-93 18:30  13-NOV-93 15:50
13-NOV-93 16:40  14-NOV-93 15:25
14-NOV-93 19:40  15-NOV-93 08:50
15-NOV-93 16:20  16-NOV-93 13:15
16-NOV-93 14:00  17-NOV-93 10:55
17-NOV-93 18:50  18-NOV-93 09:15
# No ramps beginning
# Nov 18, 1993 at 18:55
18-NOV-93 14:25  19-NOV-93 00:35
19-NOV-93 08:25  19-NOV-93 16:00
19-NOV-93 20:50  20-NOV-93 15:00
20-NOV-93 19:25  21-NOV-93 08:40
21-NOV-93 14:00  22-NOV-93 01:10
22-NOV-93 07:15  22-NOV-93 22:50
23-NOV-93 07:25  24-NOV-93 04:15
24-NOV-93 05:05  24-NOV-93 23:05
25-NOV-93 08:00  25-NOV-93 21:10
26-NOV-93 01:20  26-NOV-93 15:15
26-NOV-93 20:10  27-NOV-93 09:20
27-NOV-93 13:35  27-NOV-93 22:50
28-NOV-93 07:45  28-NOV-93 21:45
29-NOV-93 05:05  29-NOV-93 12:15
29-NOV-93 20:40  30-NOV-93 08:40
30-NOV-93 12:20  01-DEC-93 00:15
01-DEC-93 07:40  02-DEC-93 04:50
02-DEC-93 08:30  03-DEC-93 02:45
03-DEC-93 03:30  03-DEC-93 20:00
03-DEC-93 22:25  04-DEC-93 16:30
04-DEC-93 17:20  05-DEC-93 04:50
05-DEC-93 09:00  06-DEC-93 06:20
06-DEC-93 08:00  07-DEC-93 00:00
07-DEC-93 06:20  07-DEC-93 23:30
08-DEC-93 04:30  09-DEC-93 00:20
09-DEC-93 09:00  10-DEC-93 07:35
10-DEC-93 12:10  11-DEC-93 06:15
11-DEC-93 08:35  12-DEC-93 07:20
12-DEC-93 12:30  13-DEC-93 07:25
13-DEC-93 13:00  14-DEC-93 05:20
14-DEC-93 08:50  14-DEC-93 22:30
15-DEC-93 09:00  16-DEC-93 02:20
16-DEC-93 08:30  17-DEC-93 05:50
17-DEC-93 08:30  18-DEC-93 07:05
18-DEC-93 12:25  19-DEC-93 08:00
19-DEC-93 13:25  20-DEC-93 06:20
20-DEC-93 14:20  21-DEC-93 10:45
21-DEC-93 19:45  22-DEC-93 15:15
22-DEC-93 17:00  23-DEC-93 13:10
23-DEC-93 18:30  24-DEC-93 06:00
25-DEC-93 17:30  26-DEC-93 14:00
26-DEC-93 15:30  27-DEC-93 12:00
27-DEC-93 13:40  28-DEC-93 07:00
28-DEC-93 18:00  29-DEC-93 14:20
29-DEC-93 16:00  30-DEC-93 06:15
30-DEC-93 14:15  31-DEC-93 10:30
01-JAN-94 07:10  02-JAN-94 03:40
02-JAN-94 05:15  03-JAN-94 01:30
03-JAN-94 09:45  04-JAN-94 08:15
04-JAN-94 10:50  05-JAN-94 07:00
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05-JAN-94 21:30  06-JAN-94 08:20
27-JAN-94 10:30  28-JAN-94 00:00
28-JAN-94 15:00  29-JAN-94 14:00
30-JAN-94 01:25  30-JAN-94 15:20
31-JAN-94 09:00  31-JAN-94 23:00
01-FEB-94 10:05  02-FEB-94 06:30
02-FEB-94 11:15  03-FEB-94 00:50
03-FEB-94 13:10  04-FEB-94 08:10
04-FEB-94 10:30  05-FEB-94 09:50
05-FEB-94 11:45  06-FEB-94 08:00
06-FEB-94 22:30  07-FEB-94 12:20
07-FEB-94 14:10  08-FEB-94 10:17
08-FEB-94 12:10  09-FEB-94 11:30
09-FEB-94 22:50  10-FEB-94 12:45
10-FEB-94 23:55  11-FEB-94 20:30
11-FEB-94 22:10  12-FEB-94 18:50
12-FEB-94 20:15  13-FEB-94 16:25
13-FEB-94 21:30  14-FEB-94 17:50
14-FEB-94 22:30  15-FEB-94 12:30
15-FEB-94 23:50  16-FEB-94 23:05
17-FEB-94 11:05  18-FEB-94 06:50
18-FEB-94 21:00  19-FEB-94 11:35
19-FEB-94 15:40  20-FEB-94 06:20
20-FEB-94 16:45  21-FEB-94 07:00
21-FEB-94 18:20  22-FEB-94 14:30
22-FEB-94 16:30  23-FEB-94 05:40
23-FEB-94 17:40  24-FEB-94 04:30
24-FEB-94 09:20  25-FEB-94 01:40
25-FEB-94 10:30  26-FEB-94 00:30
26-FEB-94 11:40  27-FEB-94 05:00
27-FEB-94 13:00  28-FEB-94 00:00
28-FEB-94 10:50  01-MAR-94 04:15
01-MAR-94 12:05  02-MAR-94 11:00
02-MAR-94 14:00  03-MAR-94 13:10
03-MAR-94 14:15  04-MAR-94 11:00
04-MAR-94 12:20  05-MAR-94 02:50
05-MAR-94 14:15  06-MAR-94 04:00
06-MAR-94 11:40  07-MAR-94 02:00
07-MAR-94 09:45  08-MAR-94 08:30
08-MAR-94 17:20  09-MAR-94 07:30
09-MAR-94 16:00  10-MAR-94 16:20
# Periapse lower maneuvers
# March 10 16:10:18 and 17:44:35
10-MAR-94 19:50  11-MAR-94 06:45
11-MAR-94 14:20  12-MAR-94 08:00
12-MAR-94 13:00  13-MAR-94 08:30
13-MAR-94 16:40  14-MAR-94 04:00
14-MAR-94 21:20  15-MAR-94 20:50
15-MAR-94 21:30  16-MAR-94 18:50
17-MAR-94 07:10  18-MAR-94 03:00
18-MAR-94 06:45  19-MAR-94 06:40
19-MAR-94 07:20  20-MAR-94 04:30
20-MAR-94 08:40  21-MAR-94 08:40
21-MAR-94 10:00  22-MAR-94 08:15
22-MAR-94 17:00  23-MAR-94 08:00
24-MAR-94 01:20  24-MAR-94 12:00
24-MAR-94 19:00  25-MAR-94 07:00
25-MAR-94 14:00  26-MAR-94 08:10
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26-MAR-94 12:00  27-MAR-94 08:30
27-MAR-94 10:00  28-MAR-94 02:45
28-MAR-94 11:10  29-MAR-94 02:00
29-MAR-94 15:30  30-MAR-94 12:30
30-MAR-94 13:30  31-MAR-94 10:40
31-MAR-94 15:35  01-APR-94 15:25
01-APR-94 17:15  02-APR-94 16:40
02-APR-94 17:15  03-APR-94 17:30
03-APR-94 18:30  04-APR-94 17:40
# Periapse raise on April 4,
# 17:31 and 20:40
04-APR-94 22:26  05-APR-94 13:50
# Apoapse lower on April 5,
# 14:48, 17:57, 21:06
05-APR-94 22:04  06-APR-94 19:40
06-APR-94 22:25  07-APR-94 19:00
07-APR-94 19:50  08-APR-94 19:40
08-APR-94 23:50  09-APR-94 18:00
09-APR-94 18:40  10-APR-94 16:00
10-APR-94 16:40  11-APR-94 15:00
# Apoapse lower on April 11,
# 14:58, 18:05, 21:12
11-APR-94 23:08  12-APR-94 15:50
# Apoapse lower on April 12,
# 15:53, 19:00, 22:06
13-APR-94 00:39  14-APR-94 00:45
14-APR-94 01:50  15-APR-94 03:00
15-APR-94 15:30  16-APR-94 07:50
16-APR-94 15:40  17-APR-94 08:00
17-APR-94 16:20  18-APR-94 07:10
18-APR-94 11:10  19-APR-94 11:00
19-APR-94 11:50  20-APR-94 11:40
20-APR-94 15:30  21-APR-94 09:30
21-APR-94 10:25  22-APR-94 07:45
22-APR-94 08:55  23-APR-94 07:50
23-APR-94 08:00  24-APR-94 07:45
24-APR-94 08:00  25-APR-94 07:05
25-APR-94 08:00  26-APR-94 08:30
26-APR-94 08:45  27-APR-94 07:50
27-APR-94 10:00  28-APR-94 08:00
28-APR-94 08:30  29-APR-94 07:50
29-APR-94 08:00  30-APR-94 07:45
30-APR-94 09:00  01-MAY-94 07:45
01-MAY-94 08:45  02-MAY-94 03:50
02-MAY-94 08:00  03-MAY-94 07:50
03-MAY-94 08:10  04-MAY-94 07:10
05-MAY-94 08:10  06-MAY-94 07:15
06-MAY-94 08:40  07-MAY-94 07:50
07-MAY-94 08:10  08-MAY-94 07:15
08-MAY-94 08:00  09-MAY-94 04:10
09-MAY-94 08:15  10-MAY-94 08:50
10-MAY-94 09:00  11-MAY-94 08:00
11-MAY-94 12:30  12-MAY-94 10:20
12-MAY-94 10:35  13-MAY-94 09:30
13-MAY-94 09:55  14-MAY-94 08:50
14-MAY-94 09:10  15-MAY-94 08:00
15-MAY-94 08:15  16-MAY-94 07:00
16-MAY-94 08:00  17-MAY-94 08:00
17-MAY-94 08:20  18-MAY-94 07:20
18-MAY-94 08:05  19-MAY-94 07:55
19-MAY-94 08:30  20-MAY-94 04:15
20-MAY-94 07:55  21-MAY-94 06:45
21-MAY-94 07:00  22-MAY-94 02:45
22-MAY-94 06:05  23-MAY-94 06:30
23-MAY-94 06:50  24-MAY-94 05:50
24-MAY-94 06:05  25-MAY-94 05:10
25-MAY-94 05:25  26-MAY-94 06:00
26-MAY-94 06:10  27-MAY-94 06:05
27-MAY-94 08:30  28-MAY-94 07:30
28-MAY-94 07:45  29-MAY-94 06:50
29-MAY-94 08:25  30-MAY-94 07:10
30-MAY-94 12:30  31-MAY-94 11:30
# Bistatic radar:
# May 31, 12:21 to 17:14 (SCET)
31-MAY-94 17:50  01-JUN-94 16:50
01-JUN-94 17:00  02-JUN-94 16:00
02-JUN-94 16:20  03-JUN-94 15:15
03-JUN-94 15:30  04-JUN-94 14:30
04-JUN-94 15:05  05-JUN-94 13:30
# Bistatic radar:
# Jun 5, 12:57 to 24:20 (SCET)
06-JUN-94 01:00  06-JUN-94 16:10
06-JUN-94 20:15  07-JUN-94 17:00
08-JUN-94 01:00  09-JUN-94 00:00
09-JUN-94 00:30  10-JUN-94 00:30
10-JUN-94 01:30  11-JUN-94 01:30
11-JUN-94 02:00  12-JUN-94 02:10
12-JUN-94 03:00  13-JUN-94 03:00
13-JUN-94 03:45  14-JUN-94 03:45
14-JUN-94 04:30  15-JUN-94 04:30
15-JUN-94 05:15  16-JUN-94 04:50
16-JUN-94 07:30  17-JUN-94 04:45
17-JUN-94 06:45  18-JUN-94 04:00
18-JUN-94 08:50  18-JUN-94 20:55
19-JUN-94 09:25  20-JUN-94 04:50
20-JUN-94 09:15  21-JUN-94 04:40
21-JUN-94 08:50  22-JUN-94 03:30
22-JUN-94 09:00  22-JUN-94 13:30
22-JUN-94 15:20  23-JUN-94 15:20
23-JUN-94 16:05  24-JUN-94 16:05
# Bistatic radar:
# June 24, 17:15 to 23:45
25-JUN-94 00:35  26-JUN-94 00:35
26-JUN-94 01:25  27-JUN-94 01:25
27-JUN-94 02:10  28-JUN-94 02:10
28-JUN-94 03:20  29-JUN-94 03:00
29-JUN-94 03:50  30-JUN-94 03:50
30-JUN-94 09:00  01-JUL-94 04:35
01-JUL-94 09:45  02-JUL-94 08:35
02-JUL-94 09:05  03-JUL-94 06:15
03-JUL-94 10:00  04-JUL-94 07:00
04-JUL-94 09:20  05-JUL-94 09:20
05-JUL-94 09:50  06-JUL-94 08:30
06-JUL-94 14:00  07-JUL-94 12:20
07-JUL-94 13:00  08-JUL-94 06:30
08-JUL-94 09:20  09-JUL-94 06:30
```

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09-JUL-94 09:50  10-JUL-94 05:30
10-JUL-94 09:40  11-JUL-94 04:30
11-JUL-94 10:15  12-JUL-94 10:10
12-JUL-94 11:00  13-JUL-94 10:55
13-JUL-94 11:45  14-JUL-94 11:50
14-JUL-94 12:20  15-JUL-94 06:30
15-JUL-94 07:00  16-JUL-94 01:05
# Bistatic radar:
# July 16, 1:00-6
16-JUL-94 09:00  17-JUL-94 04:45
17-JUL-94 08:15  18-JUL-94 04:40
18-JUL-94 09:40  18-JUL-94 21:20
19-JUL-94 10:00  20-JUL-94 09:15
20-JUL-94 13:00  21-JUL-94 12:45
21-JUL-94 13:00  22-JUL-94 12:00
22-JUL-94 12:30  23-JUL-94 12:45
23-JUL-94 13:15  24-JUL-94 13:30
24-JUL-94 14:15  25-JUL-94 03:40
25-JUL-94 10:15  26-JUL-94 04:30
26-JUL-94 10:30  26-JUL-94 21:20
27-JUL-94 04:20  28-JUL-94 01:20
28-JUL-94 09:30  29-JUL-94 08:20
29-JUL-94 16:10  30-JUL-94 18:10
30-JUL-94 19:10  31-JUL-94 20:40
01-AUG-94 11:00  02-AUG-94 11:10
02-AUG-94 12:20  03-AUG-94 12:10
03-AUG-94 13:05  04-AUG-94 12:50
04-AUG-94 13:45  05-AUG-94 07:40
05-AUG-94 10:00  06-AUG-94 07:45
06-AUG-94 10:00  07-AUG-94 07:50
07-AUG-94 10:45  08-AUG-94 08:30
08-AUG-94 10:10  09-AUG-94 12:15
# Bistatic radar:
# Aug 9, 13:30-20:30
09-AUG-94 20:50  10-AUG-94 16:05
11-AUG-94 00:15  12-AUG-94 03:45
12-AUG-94 10:15  13-AUG-94 13:45
13-AUG-94 14:10  14-AUG-94 17:45
15-AUG-94 10:20  16-AUG-94 04:00
16-AUG-94 10:20  17-AUG-94 06:15
17-AUG-94 13:25  18-AUG-94 14:40
18-AUG-94 14:55  19-AUG-94 17:00
19-AUG-94 17:15  20-AUG-94 23:15
21-AUG-94 10:20  22-AUG-94 02:30
22-AUG-94 10:30  23-AUG-94 02:30
23-AUG-94 10:30  24-AUG-94 02:30
24-AUG-94 10:00  25-AUG-94 02:30
25-AUG-94 10:00  25-AUG-94 17:30
# Lower periapse for windmill
# Aug 25, 17:32, 19:05
25-AUG-94 19:15  26-AUG-94 08:00
26-AUG-94 10:00  27-AUG-94 06:30
27-AUG-94 10:20  28-AUG-94 13:45
28-AUG-94 13:50  29-AUG-94 14:30
29-AUG-94 14:35  30-AUG-94 15:10
# Windmill Aug 30 from
# 15:35-16:04,17:09-17:37 (SCET)
30-AUG-94 18:20  31-AUG-94 18:30
31-AUG-94 20:00  01-SEP-94 05:30
01-SEP-94 17:50  02-SEP-94 07:15
02-SEP-94 10:15  03-SEP-94 08:15
03-SEP-94 10:30  04-SEP-94 11:00
04-SEP-94 17:20  05-SEP-94 18:45
05-SEP-94 18:45  06-SEP-94 14:20
# Windmill Sep 06 from
# 14:26-14:55 (SCET)
06-SEP-94 15:00  07-SEP-94 15:05
# Windmill Sep 07 from
# 15:09-15:37 (SCET)
07-SEP-94 15:45  08-SEP-94 12:45
# Windmill Sep 08 from
# 12:46-13:15,14:19-14:48 (SCET)
08-SEP-94 14:55  09-SEP-94 13:25
# Windmill Sep 09 from
# 13:29-13:57 (SCET)
09-SEP-94 14:05  10-SEP-94 13:45
10-SEP-94 13:45  11-SEP-94 14:30
11-SEP-94 14:30  12-SEP-94 15:30
# Windmill Sep 12 from
# 15:36-16:05 (SCET)
12-SEP-94 16:10  13-SEP-94 13:05
# Windmill Sep 13 from
# 13:13-15:09 (SCET)
13-SEP-94 15:15  14-SEP-94 13:45
# Windmill Sep 14 from
# 13:51-17:30 (SCET)
14-SEP-94 17:35  15-SEP-94 16:30
15-SEP-94 17:00  16-SEP-94 17:10
16-SEP-94 17:45  17-SEP-94 17:55
17-SEP-94 18:25  18-SEP-94 18:25
18-SEP-94 19:00  19-SEP-94 22:15
19-SEP-94 23:00  21-SEP-94 00:20
21-SEP-94 11:50  22-SEP-94 15:10
22-SEP-94 15:45  23-SEP-94 15:50
23-SEP-94 16:10  24-SEP-94 16:30
24-SEP-94 16:50  25-SEP-94 17:10
25-SEP-94 17:50  26-SEP-94 17:30
26-SEP-94 19:15  27-SEP-94 18:40
27-SEP-94 19:10  28-SEP-94 16:50
# Lower periapse
# 28-SEP 16:49 and 18:21
28-SEP-94 19:50  29-SEP-94 19:50
29-SEP-94 20:30  30-SEP-94 20:30
30-SEP-94 21:00  01-OCT-94 21:15
01-OCT-94 21:40  02-OCT-94 21:45
02-OCT-94 22:15  03-OCT-94 22:45
04-OCT-94 11:20  05-OCT-94 09:00
05-OCT-94 13:15  06-OCT-94 15:00
06-OCT-94 15:30  07-OCT-94 17:40
07-OCT-94 19:15  08-OCT-94 21:45
08-OCT-94 23:00  09-OCT-94 22:30
10-OCT-94 12:00  11-OCT-94 13:00
# Termination maneuvers:
# 11-OCT-94
# 14:21,15:53,17:25,18:57,22:01
```

Magellan cycle 4 hide history.

```
First time is hide sequence epoch:
HA = Time past periapse of first hide, HH:MM:SS
LA = Length of first hide, HH:MM:SS
HB = Time past periapse of second hide, HH:MM:SS
LB = Length of second hide, HH:MM:SS
---------------------------------------------------------------------
14-SEP-1992 04:55   HA=01:51:00 LA=00:20:00
25-SEP-1992 16:30   HA=01:41:55 LA=00:25:00
09-OCT-1992 17:31   HA=01:51:25 LA=00:40:00
23-OCT-1992 18:42   HA=01:07:00 LA=00:10:00   HB=02:21:31 LB=00:10:00
06-NOV-1992 19:43   HA=00:47:01 LA=00:40:00   HB=01:54:28 LB=00:40:00
20-NOV-1992 17:27   HA=00:41:00 LA=01:54:00
18-DEC-1992 16:31   HA=00:41:00 LA=00:49:00   HB=01:46:32 LB=00:49:00
15-JAN-1993 17:38   HA=00:41:31 LA=00:35:00   HB=02:00:51 LB=00:35:00
07-MAY-1993 17:06   HA=00:41:00 LA=00:49:00   HB=01:46:30 LB=00:49:00
```

Magellan cycle 5&6 hides.

```
First time is time of first hide
on the given day.
L = Length of hide, HH:MM.
N = Time between beginning of
    hides, HH:MM:SS.
----------------------------------
17-AUG-93 12:25  L=0:20  N=1:35:00
18-AUG-93 13:40  L=0:20  N=1:35:00
19-AUG-93 21:10  L=0:30  N=3:09:00
20-AUG-93 12:53  L=0:30  N=3:09:00
21-AUG-93 04:40  L=0:30  N=3:09:00
22-AUG-93 05:52  L=0:30  N=3:09:00
22-AUG-93 15:18  L=0:30  N=3:09:00
23-AUG-93 22:50  L=0:30  N=3:09:00
24-AUG-93 14:35  L=0:30  N=3:09:00
25-AUG-93 22:05  L=0:30  N=3:09:00
11-NOV-93 22:30  L=1:10  N=3:09:00
12-NOV-93 20:35  L=1:10  N=3:09:00
13-NOV-93 18:39  L=1:10  N=3:09:00
14-NOV-93 19:53  L=1:10  N=3:09:00
15-NOV-93 17:58  L=1:10  N=3:09:00
16-NOV-93 16:02  L=1:10  N=3:09:00
17-NOV-93 20:26  L=1:10  N=3:09:00
18-NOV-93 15:21  L=1:10  N=3:09:00
19-NOV-93 10:16  L=1:10  N=3:09:00
19-NOV-93 22:55  L=1:10  N=3:09:00
20-NOV-93 20:59  L=1:10  N=3:09:00
21-NOV-93 15:55  L=1:10  N=3:09:00
22-NOV-93 07:41  L=1:10  N=3:09:00
23-NOV-93 08:54  L=1:10  N=3:09:00
24-NOV-93 07:02  L=1:10  N=3:09:00
25-NOV-93 08:14  L=1:10  N=3:09:00
26-NOV-93 03:11  L=1:10  N=3:09:00
26-NOV-93 22:06  L=1:10  N=3:09:00
27-NOV-93 13:53  L=1:10  N=3:09:00
28-NOV-93 08:48  L=1:10  N=3:09:00
29-NOV-93 06:53  L=1:10  N=3:09:00
29-NOV-93 22:39  L=1:10  N=3:09:00
30-NOV-93 14:26  L=1:10  N=3:09:00
01-DEC-93 09:21  L=1:10  N=3:09:00
02-DEC-93 10:36  L=1:10  N=3:09:00
03-DEC-93 05:34  L=1:02  N=3:09:00
04-DEC-93 00:29  L=1:02  N=3:09:00
04-DEC-93 19:24  L=1:02  N=3:09:00
05-DEC-93 11:11  L=1:02  N=3:09:00
06-DEC-93 09:12  L=1:02  N=3:09:00
07-DEC-93 07:17  L=1:02  N=3:09:00
08-DEC-93 05:23  L=1:02  N=3:09:00
09-DEC-93 09:47  L=1:02  N=3:09:00
10-DEC-93 14:09  L=1:02  N=3:09:00
11-DEC-93 09:06  L=1:02  N=3:09:00
12-DEC-93 13:28  L=1:02  N=3:09:00
13-DEC-93 14:41  L=1:02  N=3:09:00
14-DEC-93 09:37  L=1:02  N=3:09:00
15-DEC-93 10:51  L=1:02  N=3:09:00
16-DEC-93 08:11  L=1:10  N=3:09:00
17-DEC-93 09:23  L=1:10  N=3:09:00
18-DEC-93 13:44  L=1:10  N=3:09:00
19-DEC-93 14:59  L=1:10  N=3:09:00
20-DEC-93 16:12  L=1:10  N=3:09:00
21-DEC-93 20:35  L=1:10  N=3:09:00
22-DEC-93 18:40  L=1:10  N=3:09:00
23-DEC-93 19:54  L=1:10  N=3:09:00
25-DEC-93 19:11  L=1:10  N=3:09:00
26-DEC-93 17:16  L=1:10  N=3:09:00
27-DEC-93 15:20  L=1:10  N=3:09:00
28-DEC-93 19:42  L=1:10  N=3:09:00
29-DEC-93 17:47  L=1:10  N=3:09:00
30-DEC-93 15:50  L=1:10  N=3:09:00
01-JAN-94 08:49  L=1:10  N=3:09:00
02-JAN-94 06:54  L=1:10  N=3:09:00
03-JAN-94 11:16  L=1:10  N=3:09:00
04-JAN-94 12:27  L=1:10  N=3:09:00
05-JAN-94 23:10  L=1:10  N=3:09:00
27-JAN-94 12:01  L=0:58  N=3:09:00
28-JAN-94 16:22  L=0:58  N=3:09:00
30-JAN-94 03:01  L=0:58  N=3:09:00
31-JAN-94 10:31  L=0:58  N=3:09:00
01-FEB-94 11:43  L=0:58  N=3:09:00
02-FEB-94 12:56  L=0:58  N=3:09:00
03-FEB-94 14:06  L=0:58  N=3:09:00
04-FEB-94 12:09  L=0:58  N=3:09:00
05-FEB-94 13:21  L=0:58  N=3:09:00
07-FEB-94 00:00  L=0:58  N=3:09:00
07-FEB-94 15:45  L=0:58  N=3:09:00
08-FEB-94 13:48  L=0:58  N=3:09:00
10-FEB-94 00:27  L=0:58  N=3:09:00
11-FEB-94 01:39  L=0:58  N=3:09:00
11-FEB-94 23:42  L=0:58  N=3:09:00
12-FEB-94 21:46  L=0:58  N=3:09:00
13-FEB-94 22:59  L=0:58  N=3:09:00
15-FEB-94 00:11  L=0:58  N=3:09:00
16-FEB-94 01:24  L=0:58  N=3:09:00
17-FEB-94 12:04  L=0:58  N=3:09:00
18-FEB-94 22:43  L=0:58  N=3:09:00
19-FEB-94 17:37  L=0:58  N=3:09:00
20-FEB-94 18:49  L=0:58  N=3:09:00
21-FEB-94 20:00  L=0:58  N=3:09:00
22-FEB-94 18:03  L=0:58  N=3:09:00
23-FEB-94 19:15  L=0:58  N=3:09:00
24-FEB-94 11:00  L=0:58  N=3:09:00
25-FEB-94 12:12  L=0:58  N=3:09:00
26-FEB-94 13:23  L=0:58  N=3:09:00
27-FEB-94 14:35  L=0:58  N=3:09:00
28-FEB-94 12:38  L=0:58  N=3:09:00
01-MAR-94 13:50  L=0:58  N=3:09:00
02-MAR-94 15:02  L=0:58  N=3:09:00
03-MAR-94 16:13  L=0:58  N=3:09:00
04-MAR-94 14:17  L=0:58  N=3:09:00
05-MAR-94 15:28  L=0:58  N=3:09:00
06-MAR-94 13:30  L=0:58  N=3:09:00
07-MAR-94 11:33  L=0:58  N=3:09:00
08-MAR-94 19:03  L=0:58  N=3:09:00
```

```
09-MAR-94 17:06  L=0:58  N=3:09:00    20-JUN-94 12:00  L=0:25  N=3:06:00
10-MAR-94 21:14  L=0:58  N=3:08:30    21-JUN-94 09:42  L=0:25  N=3:06:00
11-MAR-94 16:04  L=0:58  N=3:08:30    22-JUN-94 10:30  L=0:25  N=3:06:00
12-MAR-94 14:03  L=0:58  N=3:08:30    22-JUN-94 17:24  L=1:05  N=3:06:00
13-MAR-94 18:20  L=0:58  N=3:08:30    23-JUN-94 18:12  L=1:05  N=3:06:00
14-MAR-94 22:37  L=0:58  N=3:08:30    25-JUN-94 02:44  L=1:05  N=3:06:00
15-MAR-94 23:45  L=0:58  N=3:08:30    26-JUN-94 03:31  L=1:05  N=3:06:00
17-MAR-94 10:16  L=0:58  N=3:08:30    27-JUN-94 04:19  L=1:05  N=3:06:00
18-MAR-94 08:16  L=0:58  N=3:08:30    28-JUN-94 05:05  L=1:05  N=3:06:00
19-MAR-94 09:24  L=0:58  N=3:08:30    29-JUN-94 05:52  L=1:05  N=3:06:00
20-MAR-94 10:32  L=0:58  N=3:08:30    30-JUN-94 09:46  L=1:05  N=3:06:00
21-MAR-94 11:40  L=0:58  N=3:08:30    01-JUL-94 10:34  L=1:05  N=3:06:00
22-MAR-94 19:05  L=0:58  N=3:08:30    02-JUL-94 11:20  L=1:05  N=3:06:00
24-MAR-94 02:28  L=0:58  N=3:08:30    03-JUL-94 12:08  L=1:05  N=3:06:00
24-MAR-94 11:40  L=0:58  N=3:08:30    04-JUL-94 09:47  L=1:05  N=3:06:00
25-MAR-94 16:10  L=0:58  N=3:08:30    05-JUL-94 10:35  L=1:05  N=3:06:00
26-MAR-94 14:09  L=0:58  N=3:08:30    06-JUL-94 14:28  L=1:05  N=3:06:00
27-MAR-94 12:06  L=0:58  N=3:08:30    07-JUL-94 15:16  L=1:05  N=3:06:00
28-MAR-94 13:14  L=0:58  N=3:08:30    08-JUL-94 09:51  L=1:05  N=3:06:00
29-MAR-94 17:30  L=0:58  N=3:08:30    09-JUL-94 10:38  L=1:05  N=3:06:00
30-MAR-94 15:30  L=0:58  N=3:08:30    10-JUL-94 11:25  L=1:05  N=3:06:00
31-MAR-94 17:15  L=0:50  N=3:08:30    11-JUL-94 12:13  L=1:05  N=3:06:00
01-APR-94 18:23  L=0:50  N=3:08:30    12-JUL-94 13:01  L=1:05  N=3:06:00
02-APR-94 19:27  L=0:50  N=3:08:30    13-JUL-94 13:48  L=1:05  N=3:06:00
03-APR-94 20:38  L=0:50  N=3:08:30    14-JUL-94 14:46  L=0:55  N=3:06:00
05-APR-94 00:55  L=0:50  N=3:08:30    15-JUL-94 09:19  L=0:55  N=3:06:00
05-APR-94 22:56  L=0:50  N=3:08:30    16-JUL-94 10:06  L=0:55  N=3:06:00
07-APR-94 00:04  L=0:50  N=3:08:30    17-JUL-94 10:53  L=0:55  N=3:06:00
07-APR-94 22:01  L=0:50  N=3:08:30    18-JUL-94 11:40  L=0:55  N=3:06:00
09-APR-94 02:17  L=0:50  N=3:08:30    19-JUL-94 12:27  L=0:55  N=3:06:00
09-APR-94 21:05  L=0:50  N=3:08:30    20-JUL-94 13:15  L=0:55  N=3:06:00
10-APR-94 18:57  L=0:50  N=3:08:30    21-JUL-94 14:02  L=0:55  N=3:06:00
12-APR-94 02:17  L=0:50  N=3:06:00    22-JUL-94 14:49  L=0:55  N=3:06:00
13-APR-94 03:10  L=0:50  N=3:06:00    23-JUL-94 15:36  L=0:55  N=3:06:00
14-APR-94 03:58  L=0:50  N=3:06:00    24-JUL-94 16:23  L=0:55  N=3:06:00
15-APR-94 17:08  L=0:50  N=3:06:00    25-JUL-94 10:58  L=0:55  N=3:06:00
16-APR-94 17:52  L=0:50  N=3:06:00    26-JUL-94 11:46  L=0:55  N=3:06:00
17-APR-94 18:40  L=0:50  N=3:06:00    27-JUL-94 06:22  L=0:55  N=3:06:00
18-APR-94 13:16  L=0:50  N=3:06:00    28-JUL-94 10:15  L=0:55  N=3:06:00
19-APR-94 14:04  L=0:50  N=3:06:00    29-JUL-94 17:14  L=0:55  N=3:06:00
20-APR-94 17:58  L=0:50  N=3:06:00    30-JUL-94 21:07  L=0:55  N=3:06:00
02-JUN-94 19:30  L=0:25  N=3:06:00    01-AUG-94 13:23  L=0:55  N=3:06:00
03-JUN-94 17:10  L=0:25  N=3:06:00    02-AUG-94 14:10  L=0:55  N=3:06:00
04-JUN-94 17:59  L=0:25  N=3:06:00    03-AUG-94 14:57  L=0:55  N=3:06:00
06-JUN-94 04:04  L=0:25  N=3:06:00    15-SEP-94 19:20  L=0:50  N=3:05:00
06-JUN-94 22:40  L=0:25  N=3:06:00    16-SEP-94 20:02  L=0:50  N=3:05:00
08-JUN-94 02:33  L=0:25  N=3:06:00    17-SEP-94 20:44  L=0:50  N=3:05:00
09-JUN-94 03:20  L=0:25  N=3:06:00    18-SEP-94 21:26  L=0:50  N=3:05:00
10-JUN-94 04:07  L=0:25  N=3:06:00    20-SEP-94 01:13  L=0:50  N=3:05:00
11-JUN-94 04:55  L=0:25  N=3:06:00    21-SEP-94 14:15  L=0:50  N=3:05:00
12-JUN-94 05:42  L=0:25  N=3:06:00    22-SEP-94 18:02  L=0:50  N=3:05:00
13-JUN-94 06:30  L=0:25  N=3:06:00    23-SEP-94 18:44  L=0:50  N=3:05:00
14-JUN-94 07:16  L=0:25  N=3:06:00    24-SEP-94 19:26  L=0:50  N=3:05:00
15-JUN-94 08:04  L=0:25  N=3:06:00    25-SEP-94 20:07  L=0:50  N=3:05:00
16-JUN-94 08:51  L=0:25  N=3:06:00    26-SEP-94 20:49  L=0:50  N=3:05:00
17-JUN-94 09:38  L=0:25  N=3:06:00    27-SEP-94 21:30  L=0:50  N=3:05:00
18-JUN-94 10:26  L=0:25  N=3:06:00    28-SEP-94 22:11  L=0:50  N=3:05:00
19-JUN-94 11:12  L=0:25  N=3:06:00    29-SEP-94 22:49  L=0:50  N=3:05:00
```

```
30-SEP-94 23:26  L=0:50  N=3:05:00
02-OCT-94 00:03  L=0:50  N=3:05:00
03-OCT-94 00:42  L=0:50  N=3:05:00
04-OCT-94 13:40  L=0:50  N=3:05:00
05-OCT-94 14:18  L=0:50  N=3:05:00
06-OCT-94 18:00  L=0:50  N=3:05:00
07-OCT-94 21:43  L=0:50  N=3:05:00
09-OCT-94 01:26  L=0:50  N=3:05:00
10-OCT-94 14:23  L=0:50  N=3:05:00
```

Appendix G

MGNP90LSAAP Gravity Coefficients to Degree and Order 40

The columns contain the following information (in order):

1. Degree n
2. Order m
3. Normalized C_{nm} x10^{-10} ($C_{20} = -J_2$)
4. Normalized S_{nm} x10^{-10}
5. Uncertainty of normalized C_{nm} x10^{-10}
6. Uncertainty of normalized S_{nm} x10^{-10}

The reference radius to use with this gravity field is 6051 km.
The gravitational mass is 324858.601 km^3/s^2.

2	0	-19716.2	.0	7.1	.0
2	1	290.3	142.8	4.7	4.6
2	2	8546.5	-998.9	9.4	9.0
3	0	7989.9	.0	3.6	.0
3	1	23479.0	5393.3	3.6	2.9
3	2	-95.0	8095.7	5.1	5.5
3	3	-1848.8	2126.4	8.6	8.0
4	0	7152.1	.0	2.7	.0
4	1	-4587.7	4911.9	2.9	2.6
4	2	1264.4	4839.8	2.2	2.1
4	3	-1744.9	-1173.6	3.1	3.0
4	4	1769.2	13762.3	6.5	6.3
5	0	-1419.7	.0	2.8	.0
5	1	1738.0	4422.0	2.6	2.3
5	2	786.3	-8674.4	2.4	2.2
5	3	5093.4	5547.1	1.9	2.0
5	4	3925.1	2382.2	3.4	3.2
5	5	2549.8	-3702.2	4.6	5.0
6	0	322.6	.0	2.8	.0
6	1	3939.2	-3380.9	2.6	2.4
6	2	1865.3	2604.9	2.3	2.1
6	3	7429.5	-2139.7	2.1	1.9
6	4	-1989.2	2597.1	2.0	1.9
6	5	2560.6	-591.0	2.3	2.3
6	6	-282.4	2158.7	4.3	4.1
7	0	-721.5	.0	3.0	.0
7	1	3059.4	-2777.1	2.9	2.5
7	2	1518.7	347.8	2.3	2.2
7	3	1669.2	-4501.0	2.1	2.0
7	4	-200.3	-876.9	2.1	2.0
7	5	316.6	-400.3	1.6	1.7
7	6	-66.0	-2794.5	2.3	2.2
7	7	-1948.6	-4835.3	3.5	3.3
8	0	-4251.3	.0	3.3	.0
8	1	-203.7	-2618.0	3.2	2.8
8	2	1627.4	-2328.5	2.7	2.5
8	3	3060.7	-53.1	2.2	2.0
8	4	-1095.8	825.8	1.9	1.8
8	5	-356.3	-176.5	1.7	1.7
8	6	-602.3	-2973.3	1.8	1.7
8	7	-317.6	-854.7	1.9	1.9
8	8	964.4	2957.7	3.1	3.1
9	0	-2353.1	.0	3.6	.0
9	1	-978.0	227.7	3.5	3.1
9	2	-2417.0	-1734.8	3.0	2.8
9	3	2586.1	139.5	2.7	2.4
9	4	-1578.9	604.1	2.2	2.1
9	5	561.5	264.0	1.7	1.7
9	6	-355.2	-1913.7	1.7	1.7
9	7	-1915.5	1457.0	1.5	1.5
9	8	947.8	1354.5	1.8	1.8
9	9	2525.7	-34.2	2.7	2.7
10	0	-2439.3	.0	3.9	.0
10	1	-1014.2	772.6	4.0	3.3
10	2	-291.7	-1359.5	3.3	3.2
10	3	-572.7	677.4	2.9	2.7
10	4	3410.5	-593.9	2.5	2.4
10	5	-2931.5	235.3	2.0	2.0
10	6	-2042.4	1730.4	1.7	1.7
10	7	-1620.2	-720.3	1.5	1.6
10	8	1400.5	1221.9	1.6	1.6
10	9	1727.0	-826.9	1.6	1.6
10	10	-431.4	161.0	2.3	2.4
11	0	495.4	.0	4.2	.0
11	1	-2304.6	-717.9	4.4	3.7
11	2	1086.7	397.9	3.8	3.5
11	3	1097.9	-1224.5	3.4	3.0
11	4	734.5	1742.7	2.8	2.8
11	5	-45.3	199.6	2.4	2.4
11	6	-68.0	1437.2	2.0	2.0
11	7	-46.4	-1133.4	1.6	1.6
11	8	399.1	292.6	1.5	1.6
11	9	67.9	827.3	1.4	1.5
11	10	374.7	215.3	1.5	1.5
11	11	1285.9	-1229.9	2.2	2.2
12	0	-442.5	.0	4.7	.0
12	1	79.7	-880.8	5.0	4.0
12	2	1314.0	-199.1	4.2	3.9
12	3	-721.5	-586.7	3.8	3.4
12	4	661.1	262.9	3.1	3.1
12	5	1780.7	-1943.5	2.7	2.8
12	6	1305.4	848.9	2.3	2.4
12	7	1075.0	-424.4	1.9	2.0
12	8	-1062.3	167.6	1.6	1.7
12	9	-584.0	23.2	1.4	1.5
12	10	1805.4	-366.0	1.4	1.5
12	11	816.9	-2326.3	1.4	1.5
12	12	-1611.1	-470.2	1.9	1.9

13	0	-1645.3	.0	5.2	.0
13	1	-186.7	-535.9	5.6	4.5
13	2	402.4	-1096.7	4.8	4.4
13	3	1054.5	-582.2	4.4	3.9
13	4	-1205.7	-1091.1	3.6	3.6
13	5	1030.6	-1227.8	3.1	3.2
13	6	-474.0	482.9	2.7	2.8
13	7	-27.0	1113.6	2.2	2.3
13	8	-17.2	383.0	1.9	2.0
13	9	148.5	1742.1	1.6	1.6
13	10	326.3	-433.4	1.4	1.4
13	11	-1122.6	-542.4	1.4	1.4
13	12	-683.4	-255.3	1.4	1.4
13	13	864.9	345.1	1.9	1.9
14	0	-330.7	.0	5.8	.0
14	1	-615.2	-1314.3	6.3	4.9
14	2	588.9	-285.2	5.5	4.9
14	3	1492.3	-751.6	5.0	4.4
14	4	283.9	-173.9	4.2	4.2
14	5	-152.0	24.5	3.6	3.8
14	6	140.5	-677.1	3.1	3.2
14	7	-318.8	-549.8	2.6	2.8
14	8	60.8	-789.2	2.2.	2.4
14	9	-223.7	-684.3	1.9	2.0
14	10	-71.8	217.3	1.6	1.6
14	11	-1191.1	-676.8	1.5	1.4
14	12	-913.3	490.2	1.4	1.3
14	13	-426.2	-408.3	1.3	1.3
14	14	-426.9	-1284.0	1.6	1.6
15	0	-712.9	.0	6.5	.0
15	1	245.5	652.0	7.0	5.4
15	2	459.9	-815.6	6.2	5.5
15	3	-112.2	567.9	5.7	5.0
15	4	473.0	-765.4	4.8	4.8
15	5	120.1	756.0	4.2	4.4
15	6	-295.3	505.6	3.6	3.9
15	7	383.1	-174.8	3.1	3.3
15	8	625.8	-22.3	2.6	2.8
15	9	-690.0	225.1	2.2	2.3
15	10	-446.1	701.0	1.9	1.9
15	11	118.9	-38.5	1.6	1.6
15	12	5.1	-37.5	1.4	1.4
15	13	485.6	-187.1	1.3	1.3
15	14	68.3	113.2	1.3	1.2
15	15	55.3	-70.5	1.6	1.6
16	0	-16.6	.0	7.2	.0
16	1	-466.6	1067.5	7.9	5.9
16	2	-319.2	797.4	7.1	6.1
16	3	359.5	271.1	6.5	5.7
16	4	551.1	719.7	5.5	5.6
16	5	-957.4	291.6	4.9	5.1
16	6	234.6	525.9	4.2	4.6
16	7	206.8	980.8	3.7	3.9
16	8	2.2	-144.6	3.1	3.4
16	9	-229.1	-846.2	2.7	2.8
16	10	103.5	144.3	2.3	2.2
16	11	327.6	51.5	2.0	2.0
16	12	519.5	-305.5	1.6	1.6
16	13	845.6	690.8	1.4	1.4
16	14	903.4	102.0	1.3	1.3
16	15	115.8	-421.4	1.3	1.2
16	16	-307.0	-1174.2	1.4	1.4
17	0	-287.1	.0	8.0	.0
17	1	-633.4	-672.4	8.9	6.5
17	2	146.0	796.9	8.0	6.8
17	3	-582.5	248.4	7.4	6.3
17	4	-305.7	-345.6	6.2	6.5
17	5	469.6	-694.8	5.7	5.8
17	6	-25.4	607.4	4.9	5.5
17	7	186.0	573.9	4.4	4.7
17	8	-425.8	-10.9	3.8	4.0
17	9	542.6	180.1	3.2	3.4
17	10	108.3	785.5	2.8	2.7
17	11	-484.4	566.3	2.3	2.2
17	12	-642.6	2.3	2.0	1.9
17	13	419.9	515.9	1.6	1.6
17	14	561.7	-233.0	1.4	1.4
17	15	466.9	-1602.1	1.3	1.3
17	16	259.6	-262.0	1.2	1.2
17	17	-789.6	11.1	1.4	1.4
18	0	-286.2	.0	8.9	.0
18	1	162.8	44.0	10.0	7.2
18	2	-51.4	25.3	9.0	7.6
18	3	20.9	-137.7	8.4	7.1
18	4	364.3	-236.5	7.0	7.4
18	5	-12.2	235.2	6.6	6.7
18	6	721.3	342.1	5.7	6.3
18	7	80.6	722.0	5.1	5.7
18	8	81.2	562.7	4.5	4.8
18	9	-344.3	406.0	3.9	4.1
18	10	-93.8	-450.5	3.4	3.3
18	11	247.1	190.9	2.9	2.8
18	12	72.5	803.6	2.3	2.3
18	13	-117.1	369.4	2.0	2.0
18	14	68.2	-699.3	1.6	1.6
18	15	130.5	-233.0	1.4	1.4
18	16	-260.7	-141.1	1.2	1.2
18	17	-70.3	-100.5	1.2	1.2
18	18	194.0	-203.8	1.3	1.2
19	0	122.1	.0	9.9	.0
19	1	502.4	-19.3	11.2	7.9
19	2	-112.4	-472.0	10.1	8.4
19	3	-327.9	-78.3	9.5	8.0
19	4	-502.6	-323.3	8.0	8.4
19	5	389.1	277.5	7.4	7.8
19	6	264.2	561.3	6.8	7.2
19	7	-185.1	-306.1	5.9	6.7
19	8	315.2	-196.6	5.5	5.7
19	9	-317.5	438.3	4.7	4.8
19	10	128.7	-362.0	4.1	4.1
19	11	610.9	-170.0	3.6	3.3
19	12	171.8	-121.8	2.9	2.8
19	13	304.2	-596.0	2.4	2.3
19	14	-184.4	-148.0	2.0	2.0
19	15	231.6	251.5	1.6	1.6
19	16	-246.0	-420.9	1.4	1.4
19	17	-296.7	178.6	1.2	1.2
19	18	394.1	189.3	1.2	1.1
19	19	544.1	-96.2	1.3	1.3
20	0	264.8	.0	11.0	.0
20	1	175.8	274.3	12.7	8.7
20	2	-38.7	-242.4	11.4	9.3
20	3	-189.2	-58.5	10.7	9.0
20	4	-92.6	-158.5	9.1	9.4
20	5	-299.6	-2.5	8.4	9.0
20	6	22.6	294.6	7.8	8.2
20	7	-25.5	-222.1	7.0	7.8
20	8	-134.1	454.0	6.3	6.8
20	9	26.4	422.2	5.7	5.8
20	10	-374.6	-140.0	4.9	4.9
20	11	-92.5	-37.6	4.3	4.1
20	12	-37.0	-34.5	3.6	3.4
20	13	374.8	62.9	3.0	2.9
20	14	-176.4	-5.1	2.4	2.3
20	15	244.7	135.0	2.1	2.1
20	16	-39.0	44.1	1.6	1.6
20	17	-357.8	458.5	1.4	1.4
20	18	285.7	888.3	1.2	1.1
20	19	106.8	-401.0	1.2	1.1
20	20	23.3	-230.6	1.1	1.1
21	0	270.0	.0	12.2	.0
21	1	195.9	114.6	14.1	9.5
21	2	118.7	-206.3	12.8	10.3
21	3	79.0	130.1	12.0	10.1

21	4	-206.8	7.3	10.3	10.6
21	5	198.9	169.9	9.5	10.2
21	6	-119.8	534.4	8.9	9.5
21	7	-218.2	107.0	8.2	8.8
21	8	144.3	134.5	7.5	8.2
21	9	539.5	102.6	6.8	6.8
21	10	147.2	114.6	6.0	5.9
21	11	-244.3	107.8	5.2	4.9
21	12	5.9	2.2	4.4	4.2
21	13	9.5	161.0	3.7	3.6
21	14	-549.0	181.4	3.0	2.9
21	15	-219.4	-189.9	2.4	2.4
21	16	174.0	-63.7	2.0	2.0
21	17	-576.0	279.1	1.7	1.7
21	18	163.5	81.0	1.4	1.4
21	19	674.3	-60.5	1.2	1.2
21	20	109.9	-51.0	1.1	1.1
21	21	325.6	-345.7	1.2	1.2
22	0	74.2	.0	13.5	.0
22	1	-48.3	-209.3	15.7	10.3
22	2	118.6	-134.6	14.3	11.4
22	3	-8.5	428.4	13.4	11.1
22	4	-52.4	-208.7	11.6	11.9
22	5	-90.9	263.5	10.9	11.3
22	6	-5.0	171.8	9.9	10.9
22	7	-290.2	-45.8	9.5	10.0
22	8	577.9	263.3	8.5	9.4
22	9	-208.9	-345.6	8.1	8.1
22	10	91.7	-249.0	7.1	6.8
22	11	-462.5	84.0	6.2	5.9
22	12	190.5	189.9	5.4	5.0
22	13	63.9	364.5	4.5	4.3
22	14	-156.0	377.6	3.7	3.6
22	15	-16.5	301.5	3.0	3.0
22	16	-81.4	83.6	2.4	2.4
22	17	-302.6	-131.9	2.1	2.1
22	18	317.7	.3	1.7	1.6
22	19	570.9	-422.1	1.5	1.4
22	20	-26.3	-362.2	1.1	1.1
22	21	81.4	-155.2	1.1	1.1
22	22	2.9	637.5	1.1	1.1
23	0	-157.1	.0	14.9	.0
23	1	82.3	92.4	17.4	11.2
23	2	72.5	49.3	15.9	12.4
23	3	16.0	-133.9	14.9	12.4
23	4	-124.9	287.3	12.8	13.3
23	5	-110.4	165.2	12.4	12.5
23	6	-349.0	58.9	11.2	12.4
23	7	268.1	-144.2	10.7	11.3
23	8	371.9	278.9	9.9	10.7
23	9	-227.3	327.8	9.2	9.5
23	10	119.2	14.6	8.6	8.1
23	11	163.3	128.9	7.4	7.0
23	12	-143.8	79.1	6.5	6.1
23	13	-351.3	-113.0	5.5	5.3
23	14	102.6	108.7	4.5	4.5
23	15	231.7	-24.7	3.8	3.8
23	16	227.8	-117.7	3.1	3.1
23	17	-93.0	24.8	2.5	2.5
23	18	27.1	222.7	2.1	2.0
23	19	95.8	-257.6	1.7	1.7
23	20	-34.2	-600.2	1.4	1.4
23	21	114.0	163.0	1.2	1.2
23	22	-123.6	240.8	1.1	1.1
23	23	339.1	104.0	1.1	1.1
24	0	33.1	.0	16.3	.0
24	1	-214.5	-196.8	19.3	12.2
24	2	-236.4	-240.9	17.6	13.6
24	3	51.5	-225.0	16.5	13.6
24	4	-168.0	231.4	14.2	14.8
24	5	-321.1	386.5	13.7	13.8
24	6	-71.0	-268.6	12.6	13.7
24	7	31.3	61.1	11.9	13.0
24	8	-9.1	183.7	11.4	11.8
24	9	-95.1	-15.3	10.6	11.1
24	10	318.4	-58.3	10.0	9.4
24	11	194.7	117.7	8.9	8.3
24	12	-326.1	-56.5	7.6	7.2
24	13	91.8	-148.5	6.6	6.3
24	14	.4	-159.4	5.6	5.4
24	15	-4.3	-183.7	4.6	4.6
24	16	-197.3	.7	3.8	3.9
24	17	122.0	-80.3	3.2	3.1
24	18	245.3	186.2	2.6	2.4
24	19	-113.9	-328.0	2.2	2.1
24	20	43.0	-173.0	1.7	1.6
24	21	-438.3	195.9	1.5	1.4
24	22	157.1	173.2	1.1	1.1
24	23	129.5	-191.7	1.1	1.1
24	24	-143.5	153.2	1.0	1.0
25	0	253.0	.0	17.8	.0
25	1	-136.4	-120.4	21.1	13.3
25	2	-162.0	-257.9	19.3	14.9
25	3	-90.8	31.8	18.2	15.0
25	4	-18.5	20.5	15.6	16.2
25	5	-205.1	-81.1	15.2	15.3
25	6	-141.9	-183.3	14.2	14.9
25	7	-40.6	-41.0	13.1	14.7
25	8	34.4	-46.9	12.8	13.2
25	9	395.4	156.4	12.0	12.5
25	10	229.7	-101.4	11.4	11.1
25	11	44.2	-48.2	10.5	9.5
25	12	-31.1	-36.1	9.1	8.6
25	13	172.9	270.7	7.8	7.4
25	14	231.3	-172.6	6.7	6.5
25	15	-257.6	-243.3	5.7	5.6
25	16	217.8	-141.8	4.7	4.7
25	17	-87.8	167.7	4.0	3.9
25	18	-147.6	-262.2	3.3	3.1
25	19	-134.4	-198.0	2.6	2.6
25	20	-145.1	269.6	2.2	2.1
25	21	15.4	-23.1	1.8	1.7
25	22	292.8	117.7	1.4	1.4
25	23	123.4	-117.3	1.1	1.2
25	24	-251.6	-1.3	1.1	1.1
25	25	121.5	-102.6	1.0	1.0
26	0	-17.4	.0	19.4	.0
26	1	-264.4	242.9	23.0	14.3
26	2	104.8	-157.4	21.1	16.2
26	3	-.7	8.8	19.9	16.2
26	4	-19.2	-89.7	17.1	17.8
26	5	-359.9	-403.5	16.6	16.8
26	6	-128.1	3.2	15.7	16.2
26	7	-90.8	-43.3	14.5	16.2
26	8	342.8	59.3	14.2	14.9
26	9	142.5	-54.3	13.5	13.7
26	10	-3.2	-138.0	12.7	12.7
26	11	-190.4	-267.9	12.1	11.1
26	12	324.9	161.8	10.5	9.9
26	13	-38.5	11.0	9.2	8.9
26	14	25.5	-134.5	7.9	7.6
26	15	68.7	16.9	6.8	6.8
26	16	-23.0	177.3	5.8	5.8
26	17	133.6	-461.4	4.8	4.8
26	18	-251.8	-134.3	4.1	3.9
26	19	238.3	-95.1	3.4	3.2
26	20	-222.6	-120.6	2.6	2.6
26	21	169.2	-70.5	2.2	2.2
26	22	15.6	-27.8	1.7	1.7
26	23	308.7	356.0	1.5	1.5
26	24	-93.4	-237.7	1.1	1.1
26	25	-20.9	-44.8	1.1	1.1
26	26	-167.4	92.6	1.0	1.0
27	0	7.8	.0	20.9	.0

27	1	-116.0	149.1	24.9	15.5
27	2	-88.0	-21.6	22.8	17.6
27	3	-250.0	32.1	21.6	17.7
27	4	102.9	-46.3	18.6	19.2
27	5	-341.9	86.1	18.1	18.3
27	6	-247.9	90.1	17.0	17.7
27	7	139.8	-119.7	16.0	17.5
27	8	128.1	-110.2	15.4	16.7
27	9	-14.3	-202.6	15.1	15.0
27	10	-165.7	57.5	14.1	14.2
27	11	210.5	208.1	13.6	12.6
27	12	-41.3	140.7	12.3	11.4
27	13	-54.8	-31.1	10.6	10.2
27	14	-149.2	-88.9	9.4	9.0
27	15	221.0	148.0	8.0	7.9
27	16	42.1	169.0	6.9	6.9
27	17	57.7	-14.1	5.9	5.9
27	18	174.1	83.9	5.0	4.8
27	19	346.9	80.9	4.2	4.1
27	20	-109.7	-166.5	3.3	3.3
27	21	150.5	59.9	2.7	2.7
27	22	23.2	-8.0	2.2	2.2
27	23	206.2	115.9	1.8	1.8
27	24	199.3	-191.2	1.5	1.5
27	25	-383.1	112.4	1.1	1.2
27	26	91.7	-78.3	1.1	1.1
27	27	-81.1	-102.8	1.0	1.0
28	0	157.9	.0	22.4	.0
28	1	62.1	-51.8	26.8	16.7
28	2	-21.8	-32.3	24.4	18.9
28	3	-57.7	-92.9	23.2	19.2
28	4	-144.2	-206.8	20.0	20.8
28	5	-22.6	26.2	19.7	19.5
28	6	-96.1	88.4	18.4	19.2
28	7	76.8	-153.4	17.4	18.6
28	8	64.8	-40.3	16.5	18.3
28	9	-206.6	-226.2	16.5	16.6
28	10	154.1	166.9	15.7	15.4
28	11	178.3	245.1	14.8	14.3
28	12	-3.9	13.4	13.9	12.8
28	13	48.0	44.7	12.3	11.8
28	14	21.1	257.5	10.8	10.4
28	15	-81.1	-73.3	9.5	9.3
28	16	-45.7	-92.1	8.1	8.1
28	17	-119.8	-48.8	7.0	7.0
28	18	7.6	40.9	6.1	5.9
28	19	-17.2	-140.6	5.1	4.9
28	20	162.1	-122.7	4.2	4.1
28	21	-34.7	-134.3	3.4	3.4
28	22	84.5	54.8	2.7	2.8
28	23	-13.3	-23.2	2.3	2.3
28	24	-11.0	29.8	1.7	1.8
28	25	-360.6	-50.7	1.5	1.5
28	26	20.7	271.3	1.1	1.1
28	27	186.8	-206.6	1.1	1.1
28	28	-34.0	54.9	.9	.9
29	0	183.4	.0	23.9	.0
29	1	95.2	80.6	28.5	18.0
29	2	-231.6	-200.9	26.0	20.4
29	3	-13.3	151.5	24.8	20.5
29	4	-142.9	-54.2	21.4	22.3
29	5	16.6	40.2	21.1	20.7
29	6	-96.5	24.1	19.8	20.5
29	7	-116.5	-14.0	18.6	19.9
29	8	-29.7	-9.0	17.8	19.4
29	9	-86.6	204.6	17.5	18.3
29	10	180.2	-62.3	17.3	16.6
29	11	-93.4	-52.2	16.1	15.7
29	12	77.6	-127.5	15.4	14.3
29	13	72.4	185.4	13.9	13.2
29	14	82.5	69.0	12.4	12.0
29	15	16.2	49.0	10.9	10.6
29	16	16.2	-19.7	9.5	9.5
29	17	-29.4	166.4	8.3	8.2
29	18	-85.8	-52.8	7.2	7.1
29	19	161.3	-124.2	6.2	6.1
29	20	-204.8	144.7	5.1	5.0
29	21	27.0	213.5	4.3	4.3
29	22	-65.9	-77.8	3.4	3.5
29	23	71.5	85.9	2.8	2.9
29	24	-13.4	115.7	2.3	2.3
29	25	21.9	-83.3	1.8	1.9
29	26	186.1	79.9	1.5	1.5
29	27	175.2	114.6	1.2	1.2
29	28	-179.0	-17.3	1.1	1.1
29	29	202.2	-71.8	.9	.9
30	0	85.7	.0	25.4	.0
30	1	5.9	34.5	29.9	19.3
30	2	-97.6	-158.3	27.4	21.9
30	3	58.5	109.0	26.2	21.7
30	4	-53.3	-72.0	22.6	23.9
30	5	156.5	-133.2	22.4	21.8
30	6	10.7	-108.1	21.0	21.5
30	7	-260.5	-.8	19.6	21.2
30	8	1.6	12.4	19.0	20.2
30	9	-84.9	-65.3	18.3	19.8
30	10	-27.6	-30.2	18.5	17.9
30	11	-253.5	-112.5	17.5	16.8
30	12	56.8	51.1	16.5	15.8
30	13	-6.6	87.0	15.4	14.5
30	14	50.5	-1.5	13.8	13.5
30	15	77.4	-188.4	12.5	12.1
30	16	-86.7	127.3	10.8	10.8
30	17	112.6	76.5	9.7	9.6
30	18	-113.7	-154.4	8.4	8.3
30	19	71.9	-69.9	7.3	7.2
30	20	-25.0	158.8	6.2	6.2
30	21	-64.7	124.3	5.2	5.2
30	22	-106.9	-28.4	4.3	4.4
30	23	-25.7	86.7	3.5	3.6
30	24	39.0	38.0	2.8	2.9
30	25	192.2	51.5	2.3	2.4
30	26	97.5	144.9	1.8	1.8
30	27	75.1	-176.5	1.6	1.6
30	28	88.1	17.5	1.1	1.1
30	29	68.8	119.6	1.1	1.1
30	30	67.1	-159.6	.9	.9
31	0	57.5	.0	26.6	.0
31	1	160.2	-57.0	31.1	20.7
31	2	-31.5	-45.7	28.6	23.3
31	3	-14.8	-10.9	27.4	23.0
31	4	39.0	-20.2	23.6	25.2
31	5	15.8	-119.8	23.7	22.9
31	6	-139.3	-89.8	22.0	22.3
31	7	-166.8	-107.7	20.6	22.4
31	8	-41.4	-18.9	20.0	21.0
31	9	-42.8	-92.2	19.2	20.6
31	10	-113.1	-40.1	19.3	19.3
31	11	100.0	-50.8	18.8	17.7
31	12	15.6	9.3	17.4	17.0
31	13	-80.0	-5.6	16.6	15.7
31	14	-56.2	-147.8	15.2	14.8
31	15	-178.2	225.2	13.9	13.5
31	16	-150.5	-42.3	12.4	12.3
31	17	-15.8	-69.1	10.9	10.9
31	18	-25.1	4.1	9.8	9.6
31	19	-168.6	15.7	8.5	8.4
31	20	46.1	-69.4	7.4	7.2
31	21	-26.3	111.4	6.3	6.3
31	22	-144.2	118.9	5.2	5.3
31	23	9.7	4.2	4.4	4.5
31	24	101.3	-87.8	3.5	3.6
31	25	85.7	13.8	2.9	3.0
31	26	50.2	-34.8	2.4	2.4

31	27	-8.5	-76.8	1.9	1.9
31	28	71.9	-105.6	1.6	1.5
31	29	101.6	-31.4	1.2	1.2
31	30	-146.7	152.9	1.1	1.1
31	31	75.3	-166.2	.9	.9
32	0	-135.8	.0	27.8	.0
32	1	144.7	94.3	32.2	22.1
32	2	-1.5	10.9	29.4	24.7
32	3	-92.9	-67.4	28.4	24.3
32	4	81.9	105.2	24.4	26.3
32	5	48.4	-31.9	24.8	23.8
32	6	75.9	-43.3	23.0	23.0
32	7	-54.8	5.7	21.2	23.0
32	8	-98.0	-163.6	20.8	22.0
32	9	-87.4	-86.9	20.0	21.1
32	10	-37.9	-87.3	19.6	20.3
32	11	-62.1	183.5	19.8	18.7
32	12	40.1	-63.6	18.5	17.9
32	13	93.4	-14.7	17.5	16.9
32	14	82.0	-43.5	16.4	15.8
32	15	32.6	140.4	15.1	14.8
32	16	-34.3	28.1	13.8	13.5
32	17	102.4	-26.8	12.3	12.3
32	18	-3.3	146.8	10.9	10.8
32	19	-27.7	130.5	9.8	9.7
32	20	25.4	42.5	8.5	8.4
32	21	156.0	65.8	7.4	7.4
32	22	-126.0	17.3	6.3	6.4
32	23	54.6	7.3	5.3	5.3
32	24	110.3	4.0	4.4	4.5
32	25	-158.4	-59.8	3.7	3.7
32	26	61.0	78.2	3.0	2.9
32	27	85.4	-82.8	2.5	2.4
32	28	-146.1	-59.0	1.9	1.8
32	29	-75.7	23.8	1.6	1.6
32	30	-95.4	119.6	1.2	1.2
32	31	170.4	224.8	1.1	1.1
32	32	-289.3	-7.3	.9	.9
33	0	10.5	.0	28.7	.0
33	1	139.2	86.0	32.9	23.4
33	2	26.7	10.5	29.8	26.2
33	3	-49.2	52.3	29.3	25.2
33	4	-32.0	25.8	24.9	27.3
33	5	144.0	38.8	25.6	24.4
33	6	114.0	-7.5	23.9	23.6
33	7	-103.0	-55.0	21.7	23.4
33	8	-127.6	-20.6	21.2	22.6
33	9	-68.9	-65.6	20.6	21.5
33	10	49.3	-186.7	20.0	20.8
33	11	5.6	-14.7	20.1	19.5
33	12	-45.0	-74.7	19.4	18.5
33	13	52.9	35.6	18.1	17.8
33	14	28.5	162.6	17.4	16.6
33	15	164.6	9.6	16.1	15.8
33	16	113.4	-12.4	14.9	14.6
33	17	-125.1	6.8	13.5	13.5
33	18	-114.5	35.4	12.3	12.2
33	19	49.0	5.3	10.9	10.8
33	20	-85.2	-14.0	9.8	9.7
33	21	-111.4	173.6	8.6	8.6
33	22	-4.6	-69.5	7.4	7.5
33	23	57.3	-107.8	6.5	6.5
33	24	36.9	31.6	5.4	5.3
33	25	-134.2	-29.4	4.6	4.5
33	26	-55.1	-17.3	3.7	3.6
33	27	144.4	-159.3	3.1	2.9
33	28	-152.1	-145.9	2.5	2.4
33	29	-53.5	200.5	2.0	1.9
33	30	71.9	105.6	1.6	1.6
33	31	34.6	229.3	1.2	1.2
33	32	-45.4	-10.8	1.1	1.1
33	33	20.0	116.3	.9	.9
34	0	-132.9	.0	29.6	.0
34	1	32.0	-7.2	33.3	24.8
34	2	98.5	4.3	30.0	27.7
34	3	-38.6	10.9	29.9	26.1
34	4	-30.4	92.0	25.3	28.3
34	5	54.8	112.8	26.2	24.8
34	6	8.9	-1.3	24.6	23.9
34	7	-3.5	23.2	22.1	23.8
34	8	-23.9	-15.3	21.5	22.8
34	9	-26.0	150.7	20.9	21.9
34	10	84.8	-40.2	20.4	20.9
34	11	93.2	-145.1	20.1	20.0
34	12	-66.5	-6.7	19.9	19.0
34	13	-46.5	104.3	18.7	18.4
34	14	-62.6	119.1	18.0	17.3
34	15	34.8	-108.6	16.9	16.4
34	16	21.4	-56.2	15.8	15.6
34	17	-12.8	40.6	14.7	14.5
34	18	63.9	-32.3	13.4	13.4
34	19	4.8	-55.4	12.3	12.2
34	20	-68.1	82.9	10.9	10.9
34	21	-16.6	-85.6	9.8	9.8
34	22	102.8	-125.7	8.5	8.7
34	23	-143.7	51.3	7.5	7.6
34	24	-33.8	-34.6	6.5	6.4
34	25	-31.1	41.2	5.5	5.4
34	26	-130.8	151.1	4.7	4.5
34	27	-145.6	23.0	3.9	3.6
34	28	-82.6	-22.1	3.1	2.9
34	29	-45.0	69.0	2.6	2.5
34	30	127.0	-53.8	2.0	1.9
34	31	63.7	127.6	1.7	1.7
34	32	-91.2	88.6	1.2	1.2
34	33	-9.3	106.9	1.1	1.1
34	34	32.3	117.1	.9	.9
35	0	-129.3	.0	30.2	.0
35	1	-24.4	82.5	33.5	26.2
35	2	61.1	6.4	30.1	29.1
35	3	-20.4	79.0	30.3	26.9
35	4	-57.1	-56.7	25.6	29.1
35	5	-.9	36.7	26.8	25.1
35	6	131.0	-43.7	25.0	24.1
35	7	21.5	24.7	22.4	24.1
35	8	47.5	136.9	21.6	22.7
35	9	-42.7	79.1	20.9	22.1
35	10	43.3	-31.5	20.7	20.9
35	11	12.3	-88.1	20.1	20.1
35	12	132.8	-58.3	19.9	19.3
35	13	-26.0	23.9	19.0	18.7
35	14	149.2	-110.3	18.3	17.9
35	15	114.5	-1.9	17.6	16.9
35	16	-82.1	90.3	16.4	16.2
35	17	-51.5	-70.4	15.5	15.3
35	18	72.2	-52.4	14.4	14.4
35	19	73.1	14.5	13.3	13.2
35	20	-59.3	28.3	12.1	12.1
35	21	-13.8	-84.7	10.8	10.9
35	22	-72.4	65.3	9.7	9.9
35	23	-53.7	-63.8	8.6	8.8
35	24	62.9	-5.5	7.6	7.6
35	25	-27.8	10.7	6.6	6.6
35	26	-111.5	122.2	5.7	5.5
35	27	-162.3	-60.3	4.9	4.6
35	28	-46.8	-38.8	4.0	3.8
35	29	64.8	128.8	3.2	3.2
35	30	162.0	-96.6	2.6	2.6
35	31	103.2	-91.9	2.0	2.0
35	32	33.9	33.9	1.7	1.7
35	33	-13.1	38.1	1.2	1.2
35	34	-110.7	-133.3	1.1	1.1
35	35	21.7	42.7	.9	.9
36	0	44.6	.0	31.0	.0

36	1	57.2	-13.8	33.4	27.7
36	2	57.7	11.9	30.0	30.3
36	3	-68.8	-167.1	30.6	27.7
36	4	-103.1	-45.3	25.8	29.7
36	5	43.2	-81.6	27.3	25.3
36	6	19.2	21.2	25.4	24.2
36	7	16.0	20.6	22.5	24.3
36	8	99.6	130.2	21.7	22.6
36	9	-74.4	34.9	20.8	22.0
36	10	12.5	-9.9	20.7	20.9
36	11	-61.2	76.1	20.1	19.9
36	12	44.5	-110.4	19.6	19.4
36	13	27.5	-51.5	19.1	18.8
36	14	73.7	-140.3	18.4	18.1
36	15	-25.9	-47.3	17.9	17.2
36	16	1.5	56.3	17.0	16.6
36	17	54.1	-65.2	16.0	15.8
36	18	17.2	59.6	15.2	15.1
36	19	-75.0	-30.1	14.1	14.2
36	20	38.3	6.7	13.1	13.1
36	21	69.0	9.9	12.0	12.1
36	22	-122.2	38.6	10.7	10.9
36	23	-15.3	41.8	9.8	9.9
36	24	59.1	.4	8.7	8.8
36	25	11.3	63.8	7.7	7.8
36	26	-27.6	4.2	6.8	6.6
36	27	8.7	86.6	5.9	5.5
36	28	44.7	19.5	5.0	4.7
36	29	48.2	60.5	4.1	4.0
36	30	37.2	77.8	3.3	3.2
36	31	2.1	-33.7	2.7	2.7
36	32	50.2	6.9	2.0	2.1
36	33	95.5	15.7	1.7	1.8
36	34	-47.3	-172.2	1.2	1.3
36	35	-1.3	133.8	1.1	1.2
36	36	-85.6	-11.5	.9	.9
37	0	-97.5	.0	31.5	.0
37	1	3.2	12.6	33.4	29.0
37	2	5.8	-73.1	29.7	31.6
37	3	61.1	-15.2	30.9	28.2
37	4	-143.5	-18.3	26.0	30.4
37	5	-17.7	46.7	27.7	25.4
37	6	45.6	8.2	25.7	24.3
37	7	95.1	27.2	22.6	24.4
37	8	-51.4	1.9	21.9	22.6
37	9	-37.9	-24.3	20.8	21.7
37	10	19.2	59.2	20.4	20.7
37	11	-46.5	-84.3	20.2	19.7
37	12	23.1	77.3	19.3	19.3
37	13	46.0	-40.0	18.9	18.8
37	14	54.2	37.0	18.4	18.2
37	15	-2.8	58.5	18.0	17.4
37	16	34.9	-56.3	17.3	16.8
37	17	17.7	63.9	16.4	16.2
37	18	-144.6	23.3	15.6	15.5
37	19	28.6	-24.4	14.8	14.9
37	20	15.4	39.2	14.0	13.9
37	21	-36.1	-.4	12.9	13.0
37	22	43.8	-60.3	11.9	12.1
37	23	-.3	33.0	10.8	10.9
37	24	107.9	-83.3	9.8	9.9
37	25	-55.8	48.9	8.8	8.9
37	26	77.3	-23.1	7.8	7.7
37	27	121.5	65.7	7.0	6.7
37	28	50.5	-8.3	5.9	5.7
37	29	18.1	-154.8	5.0	5.0
37	30	89.1	-52.6	4.1	4.1
37	31	-4.0	86.6	3.4	3.4
37	32	-17.1	39.4	2.7	2.8
37	33	43.0	-.9	2.1	2.2
37	34	-91.1	-2.4	1.7	1.8
37	35	-131.9	64.7	1.3	1.3
37	36	114.5	-26.0	1.2	1.1
37	37	-17.2	-20.1	.9	.9
38	0	-49.0	.0	32.1	.0
38	1	-69.8	39.5	33.3	30.1
38	2	45.9	58.3	29.5	32.7
38	3	8.0	23.4	31.3	28.7
38	4	-82.4	-62.9	26.1	30.9
38	5	-24.1	-70.6	28.1	25.8
38	6	6.6	15.3	26.0	24.4
38	7	34.5	-14.6	22.6	24.7
38	8	-75.2	-30.0	22.1	22.4
38	9	-79.1	3.4	20.8	21.5
38	10	11.8	14.1	20.3	20.5
38	11	42.8	-59.9	20.1	19.5
38	12	-8.7	53.5	19.1	19.2
38	13	49.4	89.5	18.6	18.7
38	14	-44.0	159.5	18.3	18.1
38	15	8.1	77.9	18.0	17.3
38	16	-13.2	20.4	17.4	16.9
38	17	1.7	104.6	16.6	16.4
38	18	8.3	2.7	16.0	15.9
38	19	-7.4	-.9	15.2	15.3
38	20	78.7	-28.2	14.6	14.6
38	21	-114.1	-23.4	13.7	13.8
38	22	-6.7	45.5	12.7	12.9
38	23	7.0	-123.6	11.9	11.9
38	24	29.0	1.1	10.8	10.8
38	25	-13.0	46.3	9.8	10.0
38	26	27.7	71.7	8.9	8.8
38	27	15.2	-45.5	8.0	7.7
38	28	.5	75.8	7.0	6.8
38	29	161.7	-40.5	6.0	5.9
38	30	-88.3	-22.5	5.1	5.1
38	31	-71.4	-3.7	4.2	4.2
38	32	22.9	-74.7	3.3	3.5
38	33	-159.6	32.5	2.8	2.9
38	34	-7.5	119.6	2.1	2.2
38	35	16.0	-48.1	1.8	1.8
38	36	15.0	-16.4	1.3	1.3
38	37	-37.8	93.0	1.2	1.2
38	38	-80.5	91.5	.9	.9
39	0	-32.2	.0	32.5	.0
39	1	-69.0	-11.8	33.3	31.0
39	2	74.2	-21.7	29.3	33.7
39	3	16.9	12.1	31.7	29.2
39	4	74.6	-70.4	26.5	31.3
39	5	-7.6	-56.5	28.4	26.1
39	6	-12.7	-107.0	26.3	24.6
39	7	126.3	-43.8	22.7	25.0
39	8	-11.3	106.4	22.4	22.4
39	9	-5.7	121.3	20.8	21.5
39	10	-94.6	63.3	20.3	20.4
39	11	.0	71.8	20.0	19.4
39	12	12.9	56.3	19.1	19.1
39	13	-57.3	85.6	18.4	18.7
39	14	-27.5	-37.4	18.2	18.0
39	15	-8.2	87.9	17.9	17.3
39	16	91.0	93.9	17.4	16.8
39	17	-2.3	70.8	16.7	16.6
39	18	72.5	-9.5	16.1	16.1
39	19	-58.9	-24.3	15.5	15.6
39	20	-26.6	-36.1	14.9	15.0
39	21	1.3	-34.3	14.3	14.4
39	22	-13.2	47.4	13.4	13.7
39	23	-79.7	-48.1	12.7	12.7
39	24	-63.5	31.1	11.8	11.8
39	25	-22.2	18.2	10.8	10.9
39	26	17.7	-33.3	9.9	9.9
39	27	-91.4	-119.1	9.1	8.8
39	28	49.0	-12.7	8.0	7.8
39	29	69.5	25.7	7.0	7.0
39	30	-64.5	-4.9	6.0	6.0

39	31	-27.3	47.2	5.2	5.2
39	32	-39.4	-39.0	4.2	4.3
39	33	-30.2	18.6	3.5	3.6
39	34	74.9	68.1	2.8	2.9
39	35	67.5	.4	2.2	2.3
39	36	-12.6	55.2	1.8	1.8
39	37	72.1	53.1	1.3	1.3
39	38	69.8	-70.9	1.2	1.2
39	39	-28.6	76.2	.9	.9
40	0	-28.9	.0	32.9	.0
40	1	-1.8	-43.9	33.5	31.7
40	2	-51.1	-36.2	29.2	34.5
40	3	30.4	-6.3	32.0	29.6
40	4	134.9	-.8	27.0	31.5
40	5	72.0	57.7	28.9	26.4
40	6	43.6	-21.0	26.7	25.0
40	7	82.9	-5.6	22.9	25.4
40	8	66.3	15.9	22.7	22.5
40	9	5.6	65.2	21.2	21.5
40	10	-64.0	21.6	20.3	20.4
40	11	-18.1	-21.8	19.9	19.4
40	12	-43.9	-10.4	19.2	19.1
40	13	26.2	33.8	18.3	18.7
40	14	8.2	18.5	18.1	18.0
40	15	90.0	85.2	17.9	17.4
40	16	72.4	13.0	17.4	16.7
40	17	76.2	-79.3	16.8	16.6
40	18	84.7	-17.5	16.2	16.3
40	19	6.7	-52.0	15.7	15.7
40	20	-4.8	-28.1	15.3	15.3
40	21	-52.2	-46.2	14.7	14.7
40	22	-36.9	-18.5	14.0	14.3
40	23	-47.3	55.3	13.4	13.3
40	24	17.0	38.0	12.6	12.5
40	25	63.2	131.0	11.7	11.8
40	26	-90.9	-56.9	10.8	10.8
40	27	-43.2	-22.3	10.1	9.8
40	28	-43.3	-39.6	9.1	8.9
40	29	-30.6	17.5	8.0	8.0
40	30	-56.9	-12.2	7.1	7.2
40	31	23.4	40.8	6.1	6.2
40	32	55.5	96.3	5.2	5.4
40	33	-39.2	44.2	4.3	4.5
40	34	-30.3	-65.7	3.5	3.6
40	35	57.1	-11.7	2.9	3.0
40	36	-34.6	-78.8	2.3	2.2
40	37	75.7	30.8	1.9	1.9
40	38	54.8	-59.6	1.3	1.3
40	39	-50.9	28.3	1.2	1.2
40	40	37.5	51.0	.9	.9

Appendix H

Correlations Between Estimated Parameters

The correlations between the nongravity global parameters and the first 5th degree and order coefficients are given in this appendix.

The following names are for the orientation of Venus:

ZACPL2 = Venus pole right ascension in Earth-Mean-Equator of J2000
ZDEPL2 = Venus pole declination in Earth-Mean-Equator of J2000
WDP2 = Venus rotation rate

The following are the Venus (2) and Earth-Moon barycenter (B) Set III parameters from Brouwer and Clemence (1969):

DMW = Δ longitude + Δ rotation about z-axis (ecliptic north, heliocentric)
EDW = eccentricity * Δ rotaton about z-axis
DA = Δ semi-major axis / semi-major axis
DE = Δ eccentricity
DP = Δ rotation about x-axis (p and q give the inclination)
DQ = Δ rotation about y-axis

And the rest of the parameters are:

2K2_2 = Love number of Venus (k_2)
GM2 = GM of Venus
J20n = Zonal coefficient of degree n
C20n0m = C_{nm}
S20n0m = S_{nm}

	ZACPL2	ZDEPL2	WDP2	DMW2	EDW2	DA2	DE2	DP2	DQ2	DMWB	EDWB
ZACPL2	1.0	1.0E-01	-3.8E-02	6.1E-03	1.7E-04	-8.3E-04	2.0E-03	-8.0E-03	3.0E-02	6.8E-03	1.0E-02
ZDEPL2		1.0	7.5E-02	-2.9E-03	-6.1E-03	-4.5E-03	-4.4E-03	-2.4E-03	1.0E-02	-2.9E-03	-2.2E-03
WDP2			1.0	7.2E-04	-8.0E-03	2.9E-03	-3.2E-03	8.4E-04	5.2E-03	1.1E-03	-9.5E-03
DMW2				1.0	-2.2E-01	8.0E-01	8.6E-02	-2.3E-01	-6.3E-02	1.0	-6.6E-02
EDW2					1.0	-3.8E-01	-1.1E-01	-1.5E-01	-3.5E-02	-2.4E-01	6.4E-01
DA2						1.0	1.4E-01	6.2E-02	-6.5E-02	8.1E-01	-3.8E-01
DE2							1.0	-1.3E-01	-8.5E-03	9.2E-02	5.2E-01
DP2								1.0	8.8E-02	-1.7E-01	-3.8E-01
DQ2									1.0	-2.7E-02	2.1E-02
DMWB										1.0	-8.2E-02
EDWB											1.0

	DAB	DEB	DPB	DQB	2K2_2	GM2	J202	C20201	S20201	C20202	S20202
ZACPL2	-9.3E-04	6.6E-04	-2.3E-02	2.2E-02	-3.9E-02	1.1E-02	-1.4E-02	-3.3E-03	1.1E-02	6.5E-02	3.5E-02
ZDEPL2	-4.7E-03	3.6E-03	-7.0E-03	7.3E-03	4.5E-02	-6.3E-03	-3.4E-02	7.2E-02	4.7E-03	-1.1E-02	4.4E-03
WDP2	3.0E-03	2.0E-03	-1.4E-03	5.4E-03	3.2E-02	1.8E-02	-1.8E-02	7.8E-02	1.6E-02	-2.2E-02	1.6E-02
DMW2	8.1E-01	2.5E-01	-1.7E-01	-1.6E-01	1.9E-02	-5.9E-03	-7.5E-03	-1.6E-03	2.9E-02	-2.0E-02	1.5E-02
EDW2	-3.9E-01	-8.2E-01	-1.6E-01	-1.3E-01	-1.4E-02	4.6E-03	1.7E-02	-4.1E-03	-1.1E-02	1.5E-02	-1.3E-02
DA2	1.0	2.6E-01	1.1E-01	-1.7E-02	4.1E-03	-5.8E-03	-4.7E-04	3.2E-03	4.9E-03	-1.4E-02	1.1E-02
DE2	1.5E-01	5.3E-01	-1.2E-01	-1.2E-02	1.0E-02	1.0E-03	5.3E-03	1.0E-03	-5.5E-02	-2.5E-02	-1.3E-02
DP2	6.9E-02	-1.4E-01	8.6E-01	5.5E-01	-3.7E-03	-3.6E-04	2.6E-03	-5.5E-03	-9.1E-03	-6.7E-03	1.0E-02
DQ2	-7.3E-02	5.3E-02	-4.3E-01	8.8E-01	2.1E-02	-2.4E-03	6.6E-03	1.5E-02	-2.6E-02	-2.0E-03	-5.8E-03
DMWB	8.2E-01	2.5E-01	-1.3E-01	-9.4E-02	2.0E-02	-5.9E-03	-6.6E-03	1.3E-04	2.8E-02	-2.1E-02	1.6E-02
EDWB	-3.7E-01	-2.1E-01	-3.9E-01	-1.4E-01	1.4E-02	2.9E-03	6.9E-03	4.8E-04	3.4E-03	-3.1E-03	-7.6E-03
DAB	1.0	2.7E-01	1.2E-01	-2.0E-02	4.4E-03	-5.7E-03	1.4E-05	4.6E-03	5.4E-03	-1.4E-02	1.2E-02
DEB		1.0	-1.3E-01	1.9E-02	2.0E-02	-2.1E-03	-1.0E-02	-3.6E-03	-3.9E-02	-2.9E-02	-1.8E-03
DPB			1.0	4.9E-02	-1.5E-02	6.3E-04	-2.0E-03	-1.3E-02	6.2E-03	-4.4E-03	1.2E-02
DQB				1.0	1.7E-02	-2.1E-03	6.7E-03	1.3E-02	-2.6E-02	-4.1E-03	-1.3E-03
2K2_2					1.0	1.9E-02	5.9E-02	2.3E-01	7.4E-02	-2.7E-01	7.4E-02
GM2						1.0	5.9E-02	-6.2E-04	-1.2E-02	-3.2E-03	-3.4E-03
J202							1.0	1.7E-01	1.6E-02	-2.3E-02	1.8E-01
C20201								1.0	2.5E-01	-4.7E-02	4.5E-02
S20201									1.0	-8.3E-02	2.0E-01
C20202										1.0	-1.5E-01
S20202											1.0

	J203	C20301	S20301	C20302	S20302	C20303	S20303	J204	C20401	S20401	C20402
ZACPL2	4.4E-03	6.8E-03	-1.8E-02	6.9E-02	3.3E-02	1.9E-02	-2.3E-03	-4.2E-03	8.9E-03	4.8E-02	5.1E-02
ZDEPL2	-4.9E-03	-5.9E-02	6.3E-05	2.3E-02	4.3E-03	4.2E-03	-8.1E-03	2.0E-02	-1.3E-02	1.8E-02	6.4E-03
WDP2	-5.3E-02	-5.1E-02	1.2E-01	-5.8E-02	-3.6E-02	-3.6E-02	-3.3E-02	-5.7E-03	-1.5E-02	9.5E-03	-1.1E-01
DMW2	1.6E-02	3.0E-03	3.0E-03	1.1E-02	-1.4E-02	1.6E-02	9.9E-03	-1.2E-02	2.6E-03	5.9E-03	-2.9E-03
EDW2	-1.3E-02	1.2E-02	-4.1E-03	-1.4E-02	1.9E-02	-1.6E-02	7.3E-03	1.5E-02	2.3E-04	-9.0E-04	1.0E-02
DA2	2.3E-03	7.2E-03	5.9E-03	7.2E-03	-3.2E-03	6.3E-03	3.0E-03	-3.7E-03	-1.0E-02	-4.6E-03	-8.1E-04
DE2	-3.6E-03	-6.3E-03	-6.7E-03	8.6E-03	2.0E-02	1.6E-03	1.2E-02	1.4E-02	-6.1E-03	-2.3E-03	2.5E-03
DP2	1.0E-02	2.5E-03	9.3E-03	4.9E-03	-2.2E-03	-3.1E-04	-1.3E-02	2.3E-04	5.6E-03	2.9E-03	-7.6E-03
DQ2	-2.6E-03	3.6E-03	-8.2E-03	-2.6E-03	-2.9E-03	6.8E-03	2.5E-02	4.8E-03	8.0E-03	-5.8E-03	2.7E-03
DMWB	1.6E-02	3.2E-03	3.4E-03	1.1E-02	-1.4E-02	1.7E-02	1.0E-02	-1.2E-02	2.8E-03	5.8E-03	-2.9E-03
EDWB	1.2E-02	1.2E-02	-5.4E-03	-1.3E-03	6.4E-03	-8.8E-03	1.3E-02	2.3E-03	1.5E-02	1.2E-02	9.2E-03
DAB	1.3E-03	7.0E-03	6.2E-03	6.9E-03	-3.2E-03	6.5E-03	3.0E-03	-3.2E-03	-1.1E-02	-4.7E-03	-6.3E-04
DEB	6.2E-03	-1.9E-02	-6.5E-03	1.4E-02	2.2E-03	2.0E-02	6.9E-03	1.3E-03	-5.9E-03	5.3E-04	-7.8E-03
DPB	1.2E-02	-7.7E-05	1.2E-02	7.4E-03	-6.8E-04	-4.5E-03	-2.6E-02	-3.1E-03	2.4E-03	5.3E-03	-8.5E-03
DQB	2.2E-03	4.2E-03	-3.2E-03	-1.6E-03	-1.6E-03	4.9E-03	1.6E-02	4.7E-03	9.2E-03	-2.1E-03	-5.8E-04
2K2_2	4.0E-02	8.6E-02	2.2E-03	1.7E-01	-5.6E-02	1.3E-01	-9.8E-02	-4.9E-02	1.4E-01	3.1E-02	2.0E-01
GM2	-7.6E-03	4.0E-03	-9.2E-03	5.2E-03	-6.2E-03	-1.6E-02	-6.2E-02	5.2E-02	-5.5E-03	3.1E-03	9.3E-03
J202	-2.3E-01	3.3E-01	1.7E-01	7.7E-02	4.6E-02	7.3E-02	-3.1E-02	3.2E-01	-7.1E-02	1.3E-02	6.3E-02
C20201	-4.4E-01	5.8E-02	-4.7E-02	-1.9E-01	-2.3E-01	-1.4E-01	6.3E-02	1.9E-02	-1.2E-01	-1.5E-01	-1.9E-02
S20201	-2.4E-01	1.4E-01	4.8E-02	9.2E-02	-4.2E-01	-1.4E-01	-2.1E-02	-6.5E-02	-7.3E-02	-1.8E-01	-1.6E-01
C20202	-3.7E-03	2.1E-01	-8.9E-02	-3.3E-01	-1.7E-01	-3.5E-01	2.0E-01	-3.4E-03	-9.8E-03	-1.2E-01	6.7E-02
S20202	-3.9E-02	1.5E-01	3.1E-01	1.2E-01	-1.7E-01	2.5E-01	-2.7E-01	-2.4E-02	8.1E-02	-5.6E-02	1.3E-01
J203	1.0	-4.3E-02	1.4E-01	1.6E-01	2.0E-01	6.1E-02	-2.0E-02	-1.7E-01	6.3E-01	4.2E-01	6.9E-02
C20301		1.0	2.8E-01	-5.3E-02	-9.8E-02	-9.3E-02	4.0E-02	-3.0E-01	4.1E-02	-5.2E-02	-1.9E-01
S20301			1.0	6.4E-02	5.2E-02	1.4E-01	1.5E-04	-1.1E-01	9.3E-02	-1.4E-01	1.2E-01
C20302				1.0	-2.6E-02	1.3E-01	-2.5E-01	4.6E-02	1.5E-01	7.8E-02	-1.4E-02
S20302					1.0	4.1E-01	6.7E-02	6.0E-02	5.0E-02	3.3E-01	1.8E-01
C20303						1.0	2.7E-02	4.2E-02	1.1E-02	1.4E-01	1.5E-01
S20303							1.0	-1.3E-02	-3.0E-02	-1.9E-02	-4.1E-02
J204								1.0	-2.0E-01	2.7E-02	1.3E-01
C20401									1.0	3.5E-01	1.2E-01
S20401										1.0	5.5E-02
C20402											1.0

	S20402	C20403	S20403	C20404	S20404	J205	C20501	S20501	C20502	S20502	C20503
ZACPL2	-4.3E-02	-5.2E-03	-6.5E-04	1.2E-01	2.5E-02	-2.1E-02	6.5E-03	-3.9E-02	-3.3E-02	-4.2E-02	1.3E-01
ZDEPL2	-4.7E-02	3.4E-02	-1.2E-04	-1.7E-02	7.8E-03	3.4E-02	-7.7E-03	-4.9E-02	3.1E-02	-3.3E-02	7.5E-02
WDP2	-5.1E-02	1.0E-02	-4.5E-02	-8.9E-02	5.4E-02	-3.0E-02	-4.5E-02	-9.7E-02	9.0E-02	-4.3E-02	-7.4E-03
DMW2	4.3E-03	-8.4E-03	1.7E-02	-9.5E-03	2.2E-02	1.4E-02	-2.1E-03	2.5E-03	1.0E-02	-8.2E-03	1.3E-02
EDW2	-6.6E-03	-6.0E-03	-8.8E-03	4.2E-03	-3.7E-03	-1.4E-02	1.3E-02	-5.4E-03	-1.5E-02	1.3E-02	-1.9E-02
DA2	-6.9E-04	-2.1E-04	3.8E-03	-6.2E-03	4.4E-03	1.3E-02	2.4E-03	1.1E-03	1.4E-02	1.9E-04	2.1E-04
DE2	-2.1E-03	-7.2E-03	-3.4E-02	-4.7E-03	-6.5E-03	6.4E-04	3.3E-03	-8.2E-04	1.5E-02	9.1E-03	-1.2E-02
DP2	-9.2E-04	-4.1E-04	1.2E-03	-4.8E-04	-7.2E-03	-2.5E-04	1.9E-03	3.2E-03	2.6E-03	-4.7E-03	-3.5E-03
DQ2	-6.9E-03	-3.8E-04	-3.3E-03	-1.1E-02	1.8E-02	-1.2E-02	2.3E-03	-1.2E-02	-5.4E-03	-1.9E-04	5.2E-03
DMWB	4.1E-03	-7.8E-03	1.6E-02	-9.7E-03	2.2E-02	1.4E-02	-1.6E-03	2.7E-03	1.0E-02	-8.4E-03	1.3E-02
EDWB	-3.6E-03	-2.5E-02	-5.1E-03	1.5E-03	1.8E-02	-2.8E-03	9.5E-03	-2.9E-03	-1.0E-02	-2.4E-03	-1.2E-02
DAB	-5.6E-04	6.1E-04	3.1E-03	-5.9E-03	4.0E-03	1.3E-02	2.7E-03	1.7E-03	1.4E-02	4.7E-04	-5.0E-05
DEB	8.3E-03	7.2E-03	-1.5E-02	-1.3E-02	-1.7E-03	8.0E-03	-8.1E-03	8.1E-04	2.6E-02	-1.0E-03	1.4E-02
DPB	2.6E-03	-8.0E-04	2.7E-03	4.7E-03	-1.5E-02	5.8E-03	-6.4E-04	8.4E-03	4.0E-03	-4.9E-03	-5.4E-03
DQB	-6.1E-03	1.6E-03	-5.1E-03	-8.3E-03	1.0E-02	-1.0E-02	3.5E-03	-8.3E-03	-2.8E-03	-2.8E-03	1.7E-03
2K2_2	7.9E-04	-1.5E-01	-1.3E-01	-2.3E-01	3.1E-01	-3.7E-02	-3.4E-02	-5.9E-02	-2.1E-02	-6.5E-02	-9.2E-02
GM2	4.6E-03	-2.2E-02	-8.2E-03	1.8E-02	-2.0E-02	1.2E-02	1.7E-02	1.0E-02	7.2E-03	-9.7E-03	-8.9E-03
J202	-2.2E-01	1.4E-02	-1.3E-01	2.0E-03	-1.3E-02	6.4E-02	2.9E-01	-2.2E-02	-7.0E-02	4.1E-04	-1.3E-01
C20201	5.9E-02	1.8E-01	2.7E-02	1.2E-01	1.6E-01	-1.0E-01	-1.7E-02	-3.8E-02	-1.1E-01	5.6E-02	-8.8E-02
S20201	1.1E-01	-9.3E-02	1.1E-01	9.4E-03	7.3E-02	-3.8E-02	1.6E-02	7.0E-03	-2.0E-02	-5.0E-03	-3.8E-02
C20202	-9.9E-02	2.0E-01	2.4E-01	1.9E-01	-7.6E-02	-2.9E-02	1.2E-01	-6.0E-02	-2.1E-01	-1.6E-02	2.7E-02
S20202	3.6E-02	-1.9E-01	-9.3E-02	3.3E-02	8.1E-02	-2.7E-02	6.0E-02	1.1E-01	-5.9E-02	-1.2E-01	-6.1E-02
J203	-8.6E-02	-4.2E-02	1.1E-02	-8.1E-02	1.1E-02	-1.2E-01	-4.7E-02	3.8E-02	3.2E-02	-3.1E-01	4.8E-02
C20301	-2.6E-01	-1.1E-02	1.3E-02	2.7E-02	9.0E-02	-7.5E-02	3.0E-01	-1.6E-01	-1.2E-01	-8.4E-02	-6.9E-02
S20301	-4.4E-01	4.5E-02	-8.5E-02	-1.8E-03	3.1E-02	-9.5E-03	1.6E-01	1.9E-01	9.9E-03	6.7E-02	-1.5E-01
C20302	-1.5E-01	-4.5E-01	-1.7E-01	-7.9E-02	1.1E-01	1.2E-01	-3.2E-02	4.1E-02	2.6E-01	-1.8E-01	1.3E-01
S20302	-9.4E-02	1.4E-01	-4.1E-01	-1.5E-01	-1.7E-01	1.6E-02	5.5E-02	-6.6E-02	1.0E-01	2.0E-01	1.5E-02
C20303	6.7E-03	-8.1E-02	-4.5E-01	-3.9E-01	-3.9E-02	3.0E-02	2.7E-04	9.6E-03	9.2E-02	3.0E-02	2.9E-01
S20303	-2.5E-02	3.5E-01	3.7E-02	-9.9E-02	-2.4E-01	-2.4E-02	8.8E-02	-2.9E-02	-5.7E-02	7.6E-02	6.8E-02
J204	1.3E-01	2.2E-02	-6.5E-02	1.6E-02	-1.1E-01	1.3E-01	5.1E-01	3.5E-01	1.1E-01	5.4E-02	-6.4E-02
C20401	-8.8E-02	-5.6E-02	1.3E-02	-3.4E-02	9.9E-02	-5.4E-01	-1.5E-01	-6.6E-02	-4.4E-01	-3.7E-01	-2.5E-02
S20401	2.5E-02	1.0E-02	-1.1E-01	-8.2E-02	-2.5E-02	-2.3E-01	4.2E-02	-2.3E-01	1.6E-01	-5.3E-01	8.3E-02
C20402	-8.6E-02	5.5E-02	-1.3E-01	-2.1E-02	6.2E-02	6.9E-02	7.0E-02	1.1E-01	-2.7E-01	1.7E-02	-3.6E-01
S20402	1.0	1.8E-02	-9.3E-03	-3.6E-02	-5.2E-02	-8.0E-02	-9.9E-02	1.1E-01	1.4E-02	-1.2E-01	1.4E-02
C20403		1.0	7.6E-03	-5.3E-03	-2.5E-01	-4.5E-02	8.6E-02	-1.4E-02	-3.0E-02	1.8E-01	-1.2E-01
S20403			1.0	3.4E-01	9.1E-02	-3.0E-02	-2.5E-02	3.5E-02	-1.2E-01	2.5E-02	3.1E-02
C20404				1.0	-6.0E-02	1.2E-02	1.1E-02	1.1E-01	-7.7E-02	6.9E-02	-2.7E-03
S20404					1.0	-3.6E-03	-3.0E-02	2.7E-02	-6.5E-02	-9.2E-02	-1.4E-02
J205						1.0	8.0E-02	1.1E-01	2.3E-01	3.3E-01	2.2E-02
C20501							1.0	2.7E-01	1.1E-01	1.8E-02	-9.7E-02
S20501								1.0	3.6E-02	1.5E-01	-4.8E-02
C20502									1.0	1.9E-02	1.7E-01
S20502										1.0	1.4E-02
C20503											1.0

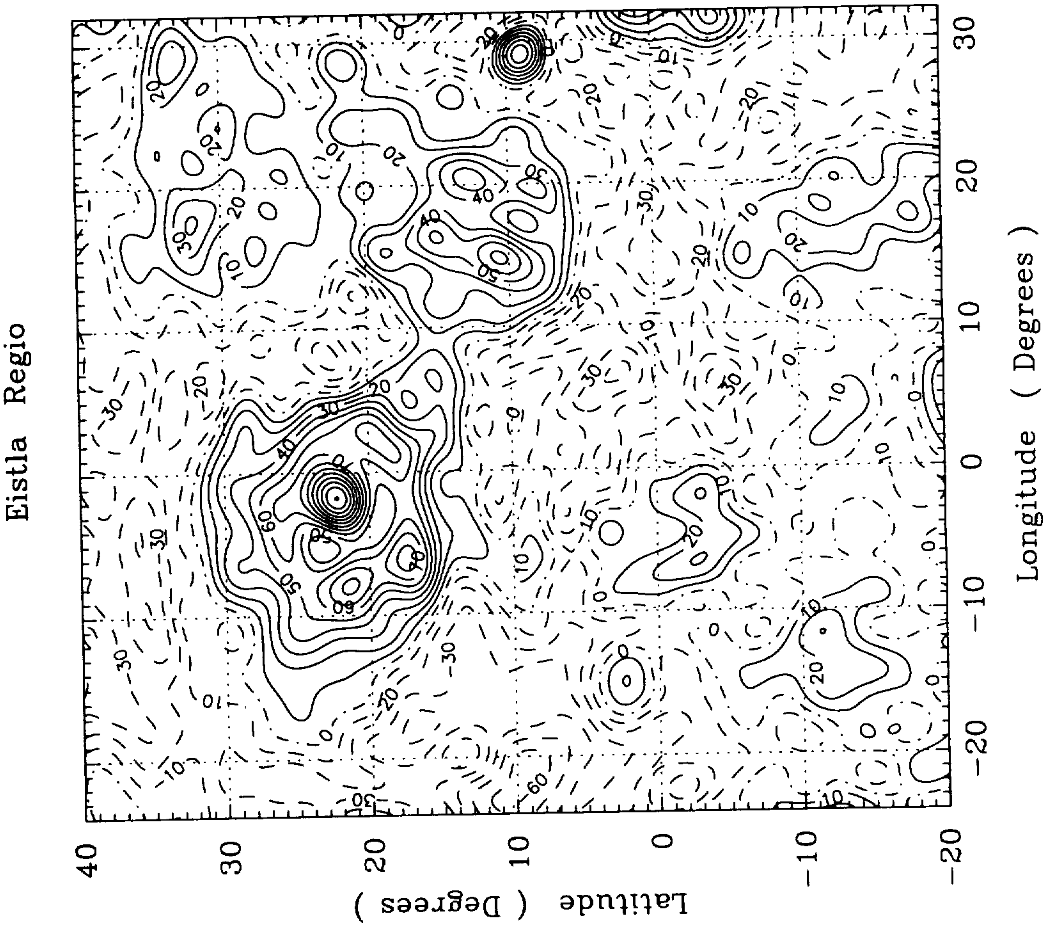
	S20503	C20504	S20504	C20505	S20505
ZACPL2	-3.5E-02	2.0E-02	-3.1E-02	-2.8E-02	-5.8E-02
ZDEPL2	-4.1E-02	-6.3E-03	1.6E-02	1.7E-02	-3.8E-03
WDP2	9.3E-02	-5.0E-02	-3.8E-03	3.4E-02	-2.1E-02
DMW2	8.8E-03	1.2E-02	-9.2E-03	-9.1E-03	-9.5E-04
EDW2	3.4E-03	-1.3E-02	1.8E-02	9.2E-04	4.0E-03
DA2	5.9E-03	3.3E-04	-7.4E-04	-5.3E-03	-5.4E-04
DE2	-5.3E-03	-1.3E-02	4.0E-02	1.3E-02	1.3E-02
DP2	-2.0E-03	2.1E-03	-3.4E-03	3.0E-03	1.5E-04
DQ2	7.4E-03	9.6E-03	1.8E-02	-1.1E-02	1.6E-02
DMWB	9.0E-03	1.2E-02	-8.5E-03	-9.2E-03	1.4E-04
EDWB	5.3E-03	-5.4E-03	2.6E-02	2.3E-03	1.7E-03
DAB	5.8E-03	-1.3E-04	-6.9E-04	-5.1E-03	1.9E-05
DEB	-5.9E-03	4.5E-03	7.7E-03	4.2E-03	9.8E-03
DPB	-5.8E-03	-2.6E-03	-1.3E-02	8.5E-03	-9.0E-03
DQB	5.5E-03	7.2E-03	1.6E-02	-7.6E-03	1.4E-02
2K2_2	-8.8E-02	1.9E-01	9.4E-02	1.4E-01	-3.3E-03
GM2	-2.3E-02	3.2E-02	5.7E-03	2.0E-02	-6.0E-02
J202	1.0E-01	-2.3E-02	6.3E-02	6.8E-02	7.7E-02
C20201	-7.8E-03	-2.3E-02	-4.6E-02	-2.8E-02	4.6E-02
S20201	6.7E-02	2.1E-02	1.6E-02	-1.9E-02	8.5E-02
C20202	1.6E-01	-8.7E-02	-1.8E-01	-2.0E-01	-4.7E-02
S20202	-6.5E-02	4.2E-02	7.1E-02	7.7E-02	8.4E-02
J203	1.3E-02	8.4E-02	-1.3E-02	4.8E-04	-7.3E-02
C20301	2.7E-01	-1.2E-02	-4.4E-02	-1.9E-03	3.0E-02
S20301	1.3E-01	-2.1E-02	-4.5E-02	1.2E-01	4.9E-02
C20302	-9.9E-03	2.5E-01	6.7E-02	9.0E-02	-1.1E-01
S20302	-3.3E-02	-1.1E-01	1.6E-01	1.3E-01	-5.5E-02
C20303	-1.5E-02	5.2E-02	3.5E-01	2.8E-01	1.3E-02
S20303	4.2E-01	-2.8E-01	4.4E-02	-2.8E-01	3.3E-01
J204	-2.1E-02	-6.5E-02	6.3E-02	2.8E-02	5.6E-02
C20401	-7.1E-03	4.8E-02	-3.9E-02	2.3E-02	-6.6E-03
S20401	3.5E-02	4.4E-02	9.5E-02	5.5E-02	-1.1E-02
C20402	-1.1E-01	1.7E-02	7.8E-03	8.3E-02	-2.5E-02
S20402	-4.1E-01	-3.6E-02	5.1E-02	-2.3E-02	2.3E-02
C20403	3.2E-03	-5.0E-01	-2.7E-02	-1.5E-01	2.0E-01
S20403	-4.3E-02	-6.3E-02	-4.7E-01	-3.3E-01	-4.8E-02
C20404	-5.8E-02	-1.0E-01	-4.4E-01	-3.1E-01	-1.6E-01
S20404	-1.1E-01	4.0E-01	-1.0E-01	-2.8E-02	-3.3E-01
J205	4.0E-03	5.5E-02	-1.2E-02	2.1E-02	-4.5E-02
C20501	1.3E-01	-7.8E-02	1.4E-02	-4.3E-03	4.2E-02
S20501	-9.8E-02	3.9E-02	-7.5E-02	2.0E-02	-1.9E-02
C20502	1.6E-02	4.2E-02	1.3E-01	3.6E-02	-4.9E-02
S20502	1.2E-02	-1.3E-01	1.5E-03	3.3E-03	-1.3E-02
C20503	2.0E-02	1.2E-01	2.9E-02	4.2E-02	-1.2E-01
S20503	1.0	-4.3E-02	7.0E-02	-1.1E-01	2.0E-01
C20504		1.0	1.2E-03	1.6E-01	-3.7E-01
S20504			1.0	3.0E-01	1.4E-01
C20505				1.0	-7.2E-02
S20505					1.0

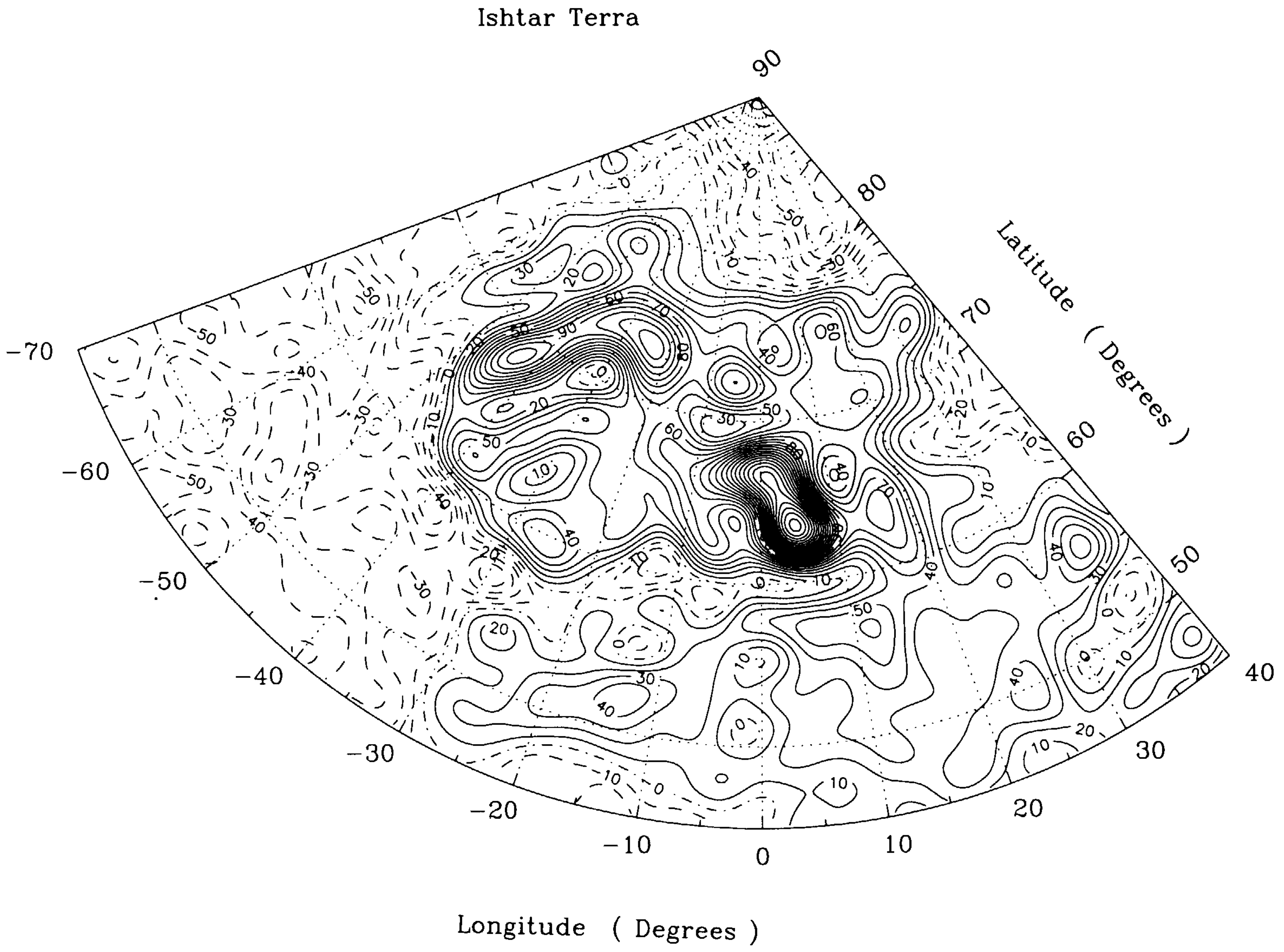
Appendix I

Regional Gravity Maps for MGNP90LSAAP

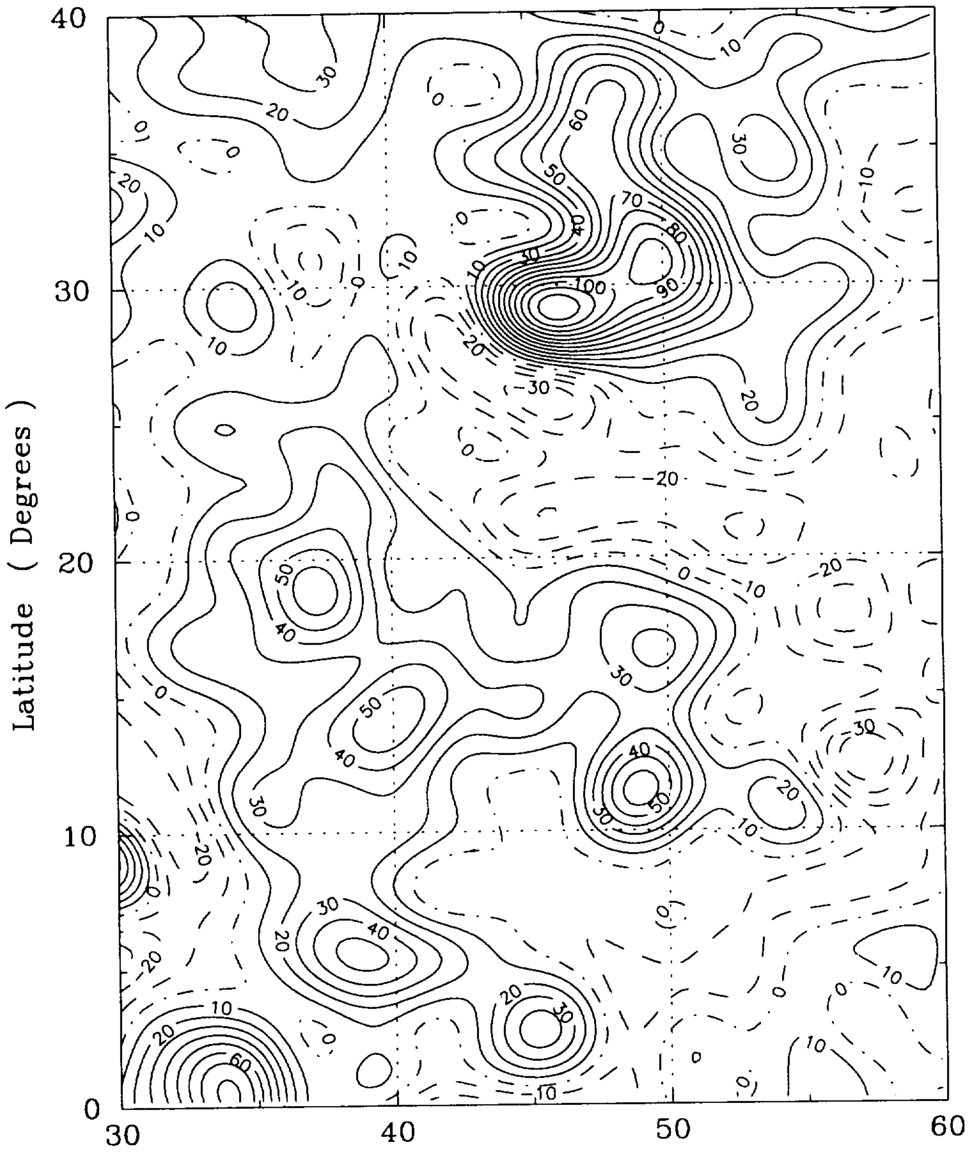
The following vertical gravity plots in milligal contours are included in this appendix:

1. Eistla Regio
2. Ishtar Terra
3. Bell Regio
4. Beta Regio
5. Atla Regio
6. Aphrodite Terra
7. Atalanta Planitia

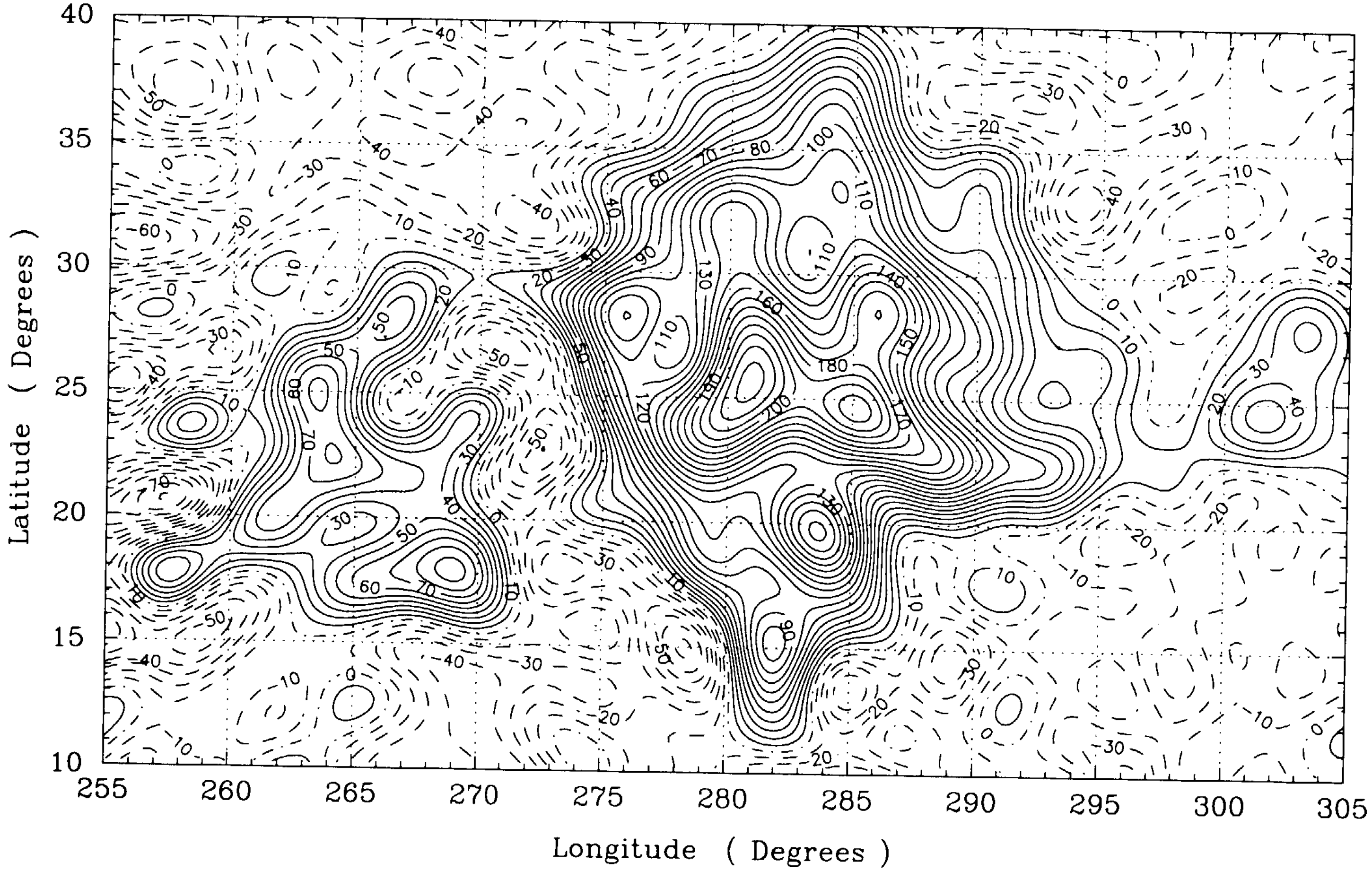

Eistla Regio
Longitude (Degrees)
Latitude (Degrees)
-20
-10
0
10
20
30
40
30
20
10
0
-10
-20


Ishtar Terra
Latitude (Degrees)
90
80
70
60
50
40
Longitude (Degrees)
−70
−60
−50
−40
−30
−20
−10
0
10
20
30
40

Bell Regio



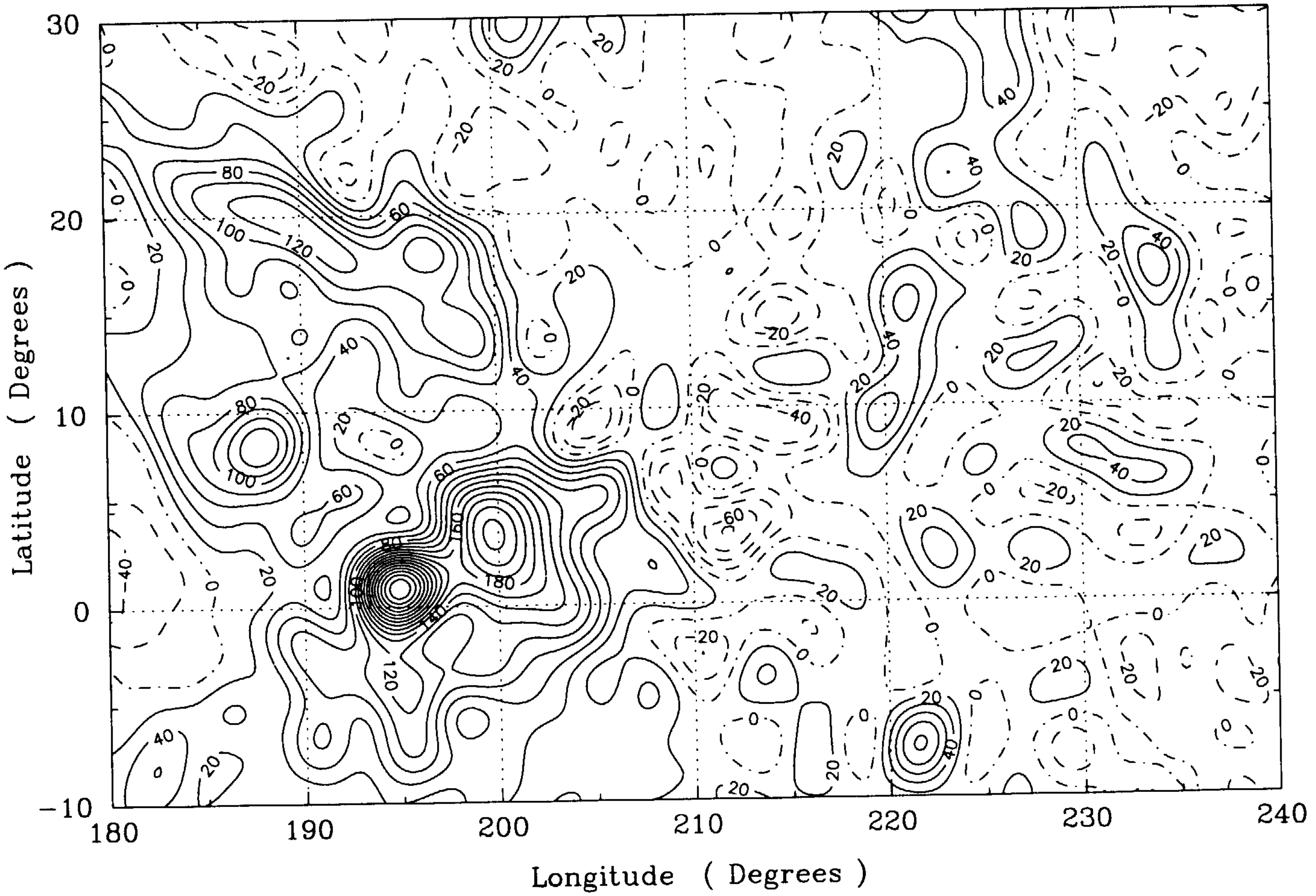
40
30
20
10
0
Latitude (Degrees)
30
40
50
60
Longitude (Degrees)
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30

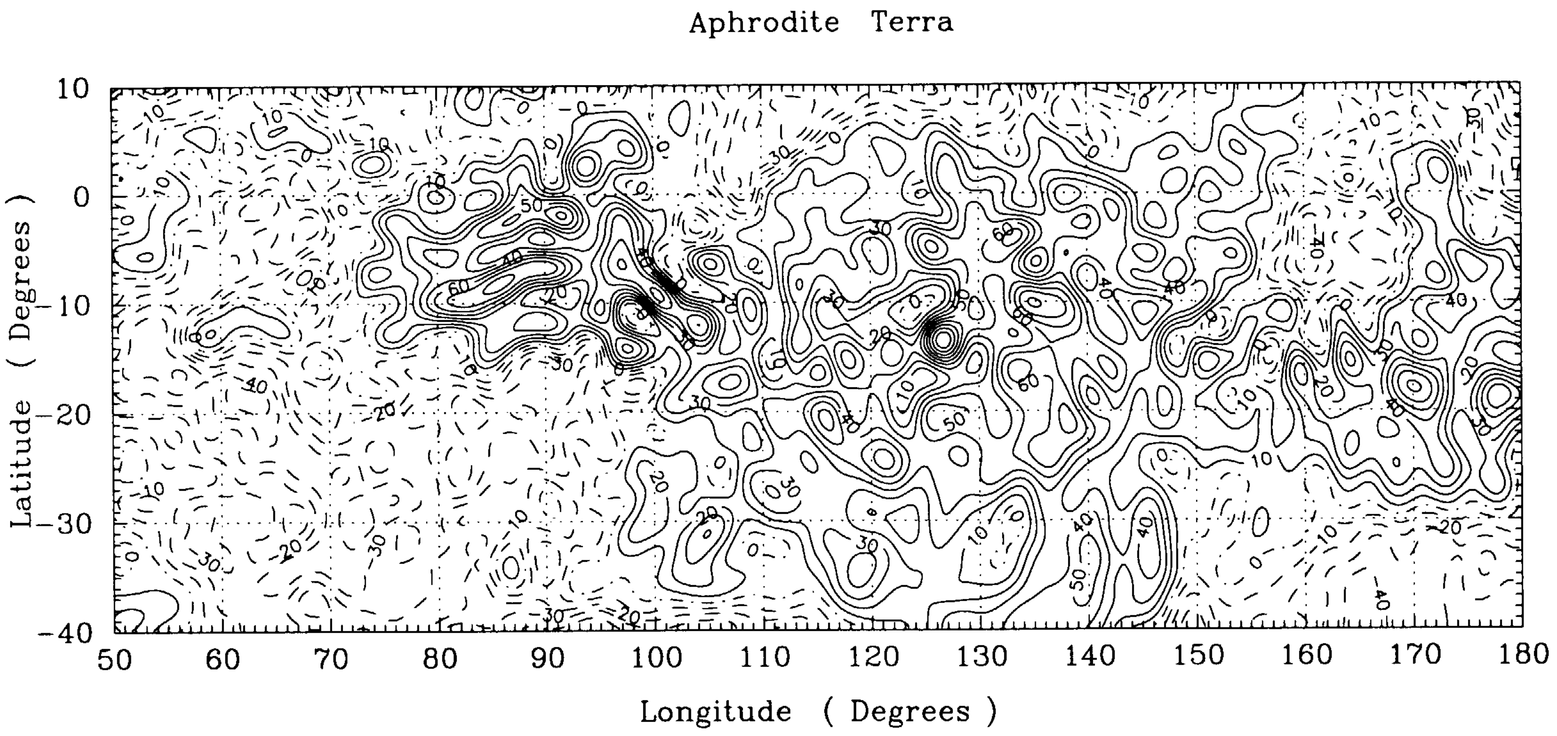


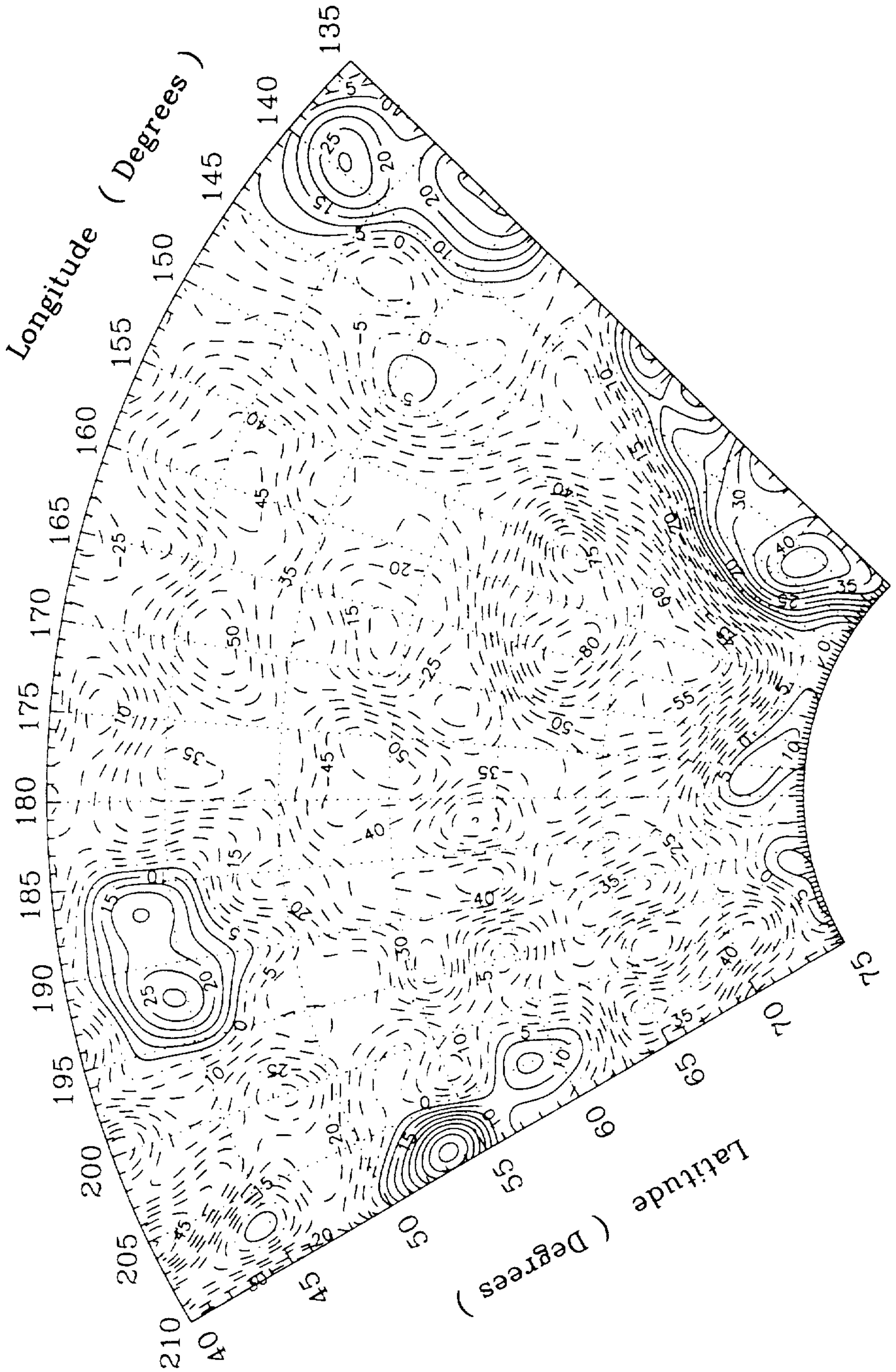
Beta Regio

Latitude (Degrees)
Longitude (Degrees)
40
35
30
25
20
15
10
255
260
265
270
275
280
285
290
295
300
305

Atla Regio


30
20
10
0
−10
Latitude (Degrees)
180
190
200
210
220
230
240
Longitude (Degrees)


Aphrodite Terra
Latitude (Degrees)
10
0
−10
−20
−30
−40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Longitude (Degrees)



Atalanta Planitia