Comparison of GSFC and JPL VLBI Modeling Software: Benchmark

O. J. Sovers
Tracking Systems and Applications Section

C. Ma
Goddard Space Flight Center

The VLBI modeling software packages CALC 6.0 (GSFC) and MASTERFIT (JPL) are compared in some detail. Theoretical model delays are calculated for a set of 120 fictitious observations which involve a variety of sources, baselines, and antennas. Discrepancies between the total delays given by the two programs are of the order of 2 cm (RMS). The modeling of antenna offsets appears to account for approximately half of this difference. Relativistic bending contributions to the delay differ by 3 cm (RMS), and there appears to be some mutual cancellation of errors involving antenna offsets, bending, and the effects of the two different Solar System ephemerides employed by CALC and MASTERFIT. This cancellation has not been completely characterized in the present study.

I. Introduction

During the past decade, parallel and independent development of the VLBI technique for geodesy and astrometry has taken place on the U.S. East and West coasts. The respective focal points for software development are the Goddard Space Flight Center (GSFC) and Jet Propulsion Laboratory (JPL). The corresponding modeling software packages are known by the names of CALC (Refs. 1, 2) and MASTERFIT (Ref. 3). Station location estimates have reached the point of 1-cm formal errors. In order to gain assurance that there are no significant differences between the modeling software at the centimeter level, we undertook a detailed comparison. Previous efforts (Ref. 4; M. G. Roth, private communication, 1981) were not comprehensive enough to provide detailed assessments of model differences at this level. At the time that this study was initiated (late 1984), there still existed discrepancies as large as 10 cm. Most of these appear to have been eliminated by the implementation of the Yoder short-period tidal UT1 corrections and the Shapiro relativistic corrections in going from version 5.0 to 6.0 of CALC.

The method we employ entails comparison of model delays yielded by CALC and MASTERFIT. Both are the versions in use on the GSFC HP 1000 and JPL VAX 11/785 computers in the Spring of 1985, identified as CALC 6.0 and MFIT.EXE;333, respectively. The MASTERFIT models, with minor exceptions, correspond to those described by Fanselow and Sovers (Ref. 3). A set of 120 fictitious ("benchmark") observations was generated, employing hourly alternating observations of three sources with five baselines on April 1, 1982.

If care is taken to make the two models identical to the extent permitted by the existing code, differences of calculated delays are found to be 9-50 ps (3-15 mm), even for baselines nearly the length of an Earth diameter. To some extent, this agreement results from partial cancellation of larger discrepancies in parts of the models. In particular, apparent differences as large as 250 ps (8 cm) in the relativistic part of the delay remain unexplained. The comparison process uncovered one centimeter-level bug in MASTERFIT, and slight inadequacies of two models in CALC and MASTERFIT. The former involved inconsistent coordinate systems used to estimate the pole tide, while the latter concerned a singularity in the correction of the elevation angle for estimating the antenna axis offset effect in CALC, and corrections for a nonspherical Earth in the local to geocentric transformations of tidal displacements in MASTERFIT.

It is emphasized that the present benchmark study does not address delay rates, observable partials, or least-squares parameter estimation. We hope to compare all of these aspects of the software in the future. Indirect evidence from a variety of fits to real data, however, implies that no serious discrepancies exist. For example, universal time and polar motion values derived from independent experiments by the two groups are in good agreement with each other, as well as with the BIH compilation (Ref. 5); a transcontinental baseline measurement agrees at the centimeter level (Refs. 6, 7); both groups obtain a value close to 1.0 for the parametrized post-Newtonian theory gamma factor (Refs. 8, 7); positions of extragalactic radio sources derived from independent measurements by GSFC and JPL agree essentially within formal error estimates (Ref. 9).

Previous attempts at software comparison were not strictly analogous to the present study. Fliegel (Ref. 4) did an overall comparison of baseline results for Mobile VLBI experiments, but did not isolate components of the model. M. G. Roth (private communication, 1981) did investigate details of the JPL and GSFC models, but abandoned the comparison at the nanosecond level because both sets of code were in a state of flux at the time. In particular, MASTERFIT was being translated from an IBM to a VAX computer, while simultaneously incorporating the IAU 1984 resolutions.

II. Benchmark Observations

Three fictitious sources and five idealized stations were chosen for a set of benchmark observations on five baselines at hourly intervals over a 24-hour period: 1 April 1984 0 hr to 23 hr UT. The J2000 source coordinates are given in Table 1. They were chosen to span a wide range of right ascensions and declinations. The time of year provides a high probability of observing sources near the Sun, and thus magnifies discrepancies in gravitational bending models.

Station cartesian coordinates, antenna types, and axis offsets are listed in Table 2. Two of the stations (Haystack and Sweden) are routinely employed in the IRIS/POLARIS experiments (Ref. 10) while another two (Goldmars and Canberra) correspond to the approximate positions of the Deep Space Network American and Australian stations, and the last station (Pole) is entirely fictitious. The antenna characteristics were arbitrarily chosen to include a variety of types and large axis offsets to expose and magnify discrepancies in these aspects of modeling.

Table 3 shows the five baselines employed for hourly alternating observations of the sources of Table 1. Their lengths range from 4000 to 12,000 km: the Canberra-Sweden baseline is nearly equal to an Earth diameter.

Table 4 gives the observing schedule for each of the five baselines, making a total of 120 benchmark observations. It should be noted that approximately half of these observations force one or both stations to observe at negative elevation angles. Since the tropospheric delay model is turned off in both programs, and both assume a transparent Earth, this presents no problem. Magnitudes of the calculated delays range between 0.6 and 38.8 ms for these 120 observations.

III. Comparison of Model Delays

We first enumerate the known discrepancies in CALC and MASTERFIT models, in order to be able to present more systematic comparisons. These are as follows:

(1) The Solar System ephemerides are different: CALC uses a version of the MIT PEP ephemeris rotated to J2000, while MASTERFIT uses the JPL ephemeris DE 200 (Ref. 11). Major effects of these differences are expected to be manifested in the solid Earth tide and gravitational bending contributions to the delay. Differences in the magnitudes of Earth-Sun vectors are of the order of 800 m, for example.

(2) The treatment of the general relativistic bending of the ray path is totally different. In addition, MASTERFIT includes the Earth and all planets, while CALC only takes account of the Sun. The bending effect of the Earth is as large as 155 ps for the benchmark observations, while other planets contribute a maximum of 0.3 ps.

(3) CALC corrects the source position employed in modeling antenna offset contributions for tropospheric bending with a simplified (tangent of the elevation angle) function. This correction uses nominal zenith troposphere values, and is present even when the tropospheric delay modeling is turned off. The standard MASTERFIT model ignores this, since it amounts to only a few mm at a 6-deg elevation for a 10-m offset.

A. Input Model Parameters

Care was taken to ensure that all parameters entering the two models were identical. In addition to the source and station parameters of Tables 1 and 2, these include the following:

Velocity of light	=	299792458 m/s
Relativistic gamma factor	=	1.0
Earth equatorial radius	=	6378.14 km
Flattening factor	=	298.257
Solid Earth tide Love numbers	=	0.609, 0.0852
Zenith tropospheric delay	=	0 (all stations)

Both CALC and MASTERFIT obtain pole position and universal time values for each observation by interpolating input tables. Since the interpolating functions are different (cubic and linear, respectively), we made sure that identical values were obtained by preparing idealized linear input tables in both cases. Table 5 shows the values of polar motion and UT1-UTC employed for the benchmark calculations. Differences in the interpolation algorithms are expected to contribute no more than a few mm to theoretical delay differences in unfavorable cases.

For the sake of completeness, Table 6 gives the parameters (amplitudes and phases) in the 11-component ocean loading model used in the benchmark calculations. Only the Haystack and Goldmars stations are assigned ocean loading displacements, and these are solely radial, since CALC 6.0 does not treat the longitudinal components. The absence of horizontal ocean loading displacements is expected to contribute only a few mm to calculated delays.

B. Comparison of Calculated Delays

Details of the observation-by-observation calculated delays are relegated to the figure in the Appendix. Note that the delays for one observation (No. 85) differ by approximately 130 ns. This is due to the above mentioned CALC correction of source position for tropospheric refraction, which is unreasonably large for the North Pole station, whose elevation angle is -0.012 deg. This observation has been excluded from all RMS quantities quoted below. We note that the overall discrepancy (excluding negative elevations) is 67 ps (20 mm). The CALC-MASTERFIT difference does not appear to be correlated with baseline length, with the worst agreement (92 ps = 28 mm RMS) occurring for one of the shortest baselines (Goldstone to the North Pole).

In view of the above mentioned known model differences, we tried to isolate the major factor responsible for the 2-cm delay discrepancies. Three further comparisons were made, in which the effects of differences in tidal, relativistic bending, and antenna offset models were eliminated in turn. For tides, the MASTERFIT contributions were subtracted from the MASTERFIT model delays and the CALC contributions added; for bending, all contributions except that of the Sun were subtracted from MASTERFIT; for antenna offsets, the axis offsets of Table 2 were set to zero in both programs. A further comparison included all three modifications simultaneously. The results are tabulated in Table 7 ("all" and "+ only" indicate all 120 observations, and only those with positive elevation angles at both stations, respectively). It is clear that discrepancies in tidal and bending models make little if any contribution to the raw differences.

The identical treatment of antenna offsets, on the other hand, is seen to reduce the RMS difference to 40% of its raw value, and the maximum difference by nearly a factor of 5. It must be stressed that the benchmark comparison is a stringent test, involving a majority of observations at elevations and antenna offsets which would never be encountered in real data. In view of this, the 26 ps RMS and 50 ps maximum discrepancies (approximately 8 and 15 mm) are gratifyingly small.

Further numerical quantification of CALC-MASTERFIT differences was performed in three areas: tidal, gravitational bending, and tropospheric contributions. Table 8 presents a comparison of delay contributions and station (baseline) displacements due to the various tidal components, for all 120 observations. In contrast to Table 7, which exhibits only the total model delays, Table 8 is concerned with component parts of the delays. It is seen that only the solid Earth tide differences are substantial, while there is nearly perfect agreement for the $K1$ correction (Ref. 12), pole tide, and ocean loading. At present it is not clear whether the solid tide differences are due to ephemeris differences or to computational algorithms.

For relativistic bending, the understanding and reconciliation of the two models will require more work than we were prepared to perform in this study. We attempted, however, to isolate the components of the delay that depend solely on the Parametrized Post-Newtonian (PPN) parameter gamma, namely the relativistic bending. When this is done, comparison shows that the RMS relativistic delay difference is 92 ps (3 cm), with a maximum of 254 ps (8 cm). Contrast this with the corresponding numbers for agreement of total delay: 21 ps (6 mm) and 49 ps (15 mm).

While tropospheric delay is outside the scope of this comparison, and is not included in any of the comparisons discussed above, we took the opportunity to compare this aspect of modeling as well. Both CALC and MASTERFIT were set to employ the model of Chao (Ref. 13), which is now known to be inadequate for VLBI purposes. The RMS CALC-MASTERFIT tropospheric delay difference for the benchmark set was 28 ps, with a maximum of 106 ps (8 and 32 mm, respectively). Only observations at positive elevation angles were included. These results are surprisingly large for a formula which is algebraically simple; at present, no explanation is evident. Naturally a large contribution to the discrepancy is made by the substantial fraction of benchmark observations that involve very low elevation angles. We hope to perform a more thorough comparison of the new Lanyi (Ref. 14) and CFA (Ref. 15) tropospheric mapping functions in the near future.

IV. Conclusions

Comparison of GSFC and JPL VLBI software shows agreement at the 1-2 cm level. Included are all components of the model in common use at the beginning of 1985, with the exception of ionospheric and tropospheric delays. Three areas of remaining discrepancy are the use of different Solar System ephemerides, different methods of estimating gravitational bending, and different corrections for tropospheric refraction in calculating antenna offset effects. Millimeter-size discrepancies could also potentially arise due to the difference in interpolating algorithms for UT1 and polar motion *a priori* values. It is hoped to reconcile these differences during the coming year, and to perform similar comparisons of the partial derivative and parameter estimation sections of the respective codes.

References

1. Ryan, J., D. Gordon and C. Ma, *CALC 6.0 Released*, Goddard Space Flight Center, Technical Memorandum, Jan. 15, 1985.
2. GSFC VLBI Group, *CALC, Version 6.0*, Goddard Space Flight Center, Greenbelt, Maryland, 30 Jan. 1985.
3. Fanselow, J. L. and O. J. Sovers, Observation Model and Parameter Partials for the JPL VLBI Parameter Estimation Software "MASTERFIT" – V2.0, *JPL Publication 83-39, Rev. 1*, Jet Propulsion Laboratory, Pasadena, Calif., 1985.
4. Fliegel, H. F., Session III of the VLBI/Laser Intercomparison Task of the NASA Crustal Dynamics Project, *JPL Publication 81-96*, Jet Propulsion Laboratory, Pasadena, Calif., 1981.
5. Eubanks, T. M., M. A. Spieth and J. A. Steppe, Accuracy of Radio Interferometric Estimates of Earth Rotation, *TDA Progress Report 42-80*, pp. 229-235, Jet Propulsion Laboratory, Pasadena, Calif., 1985.
6. Rogers, A. E. E., R. J. Cappallo, H. F. Hinteregger, J. I. Levine, E. F. Nesman, J. C. Webber, A. R. Whitney, T. A. Clark, C. Ma, J. Ryan, B. E. Corey, C. C. Counselman, T. A. Herring, I. I. Shapiro, C. A. Knight, D. B. Shaffer, N. R. Vandenberg, R. Lacasse, R. Mauzy, B. Rayhrer, B. R. Schupler, and J. C. Pigg, Very-Long-Baseline Interferometry: The Mark III System for Geodesy, Astrometry and Aperture Synthesis, *Science 219*, 51-54, 1983.
7. Sovers, O. J., J. B. Thomas, J. L. Fanselow, E. J. Cohen, G. H. Purcell, Jr., D. H. Rogstad, L. J. Skjerve and D. J. Spitzmesser, Radio Interferometric Determination of Intercontinental Baselines and Earth Orientation Utilizing Deep Space Network Antennas – 1971 to 1980, *J. Geophys. Res. 89*, 7597-7607, 1984.

8. Robertson, D. S. and W. E. Carter, Relativistic Deflection of Radio Signals in the Solar Gravitational Field Measured with VLBI, *Nature 310*, 572-574, 1984.

9. Fanselow, J. L., O. J. Sovers, J. B. Thomas, G. H. Purcell, Jr., E. J. Cohen, D. H. Rogstad, L. J. Skjerve and D. J. Spitzmesser, Radio Interferometric Determination of Source Positions Utilizing Deep Space Network Antennas – 1971 to 1980, *A. J. 89*, 987-998, 1984.

10. Carter, W. E., and D. S. Robertson, IRIS Earth Rotation and Polar Motion Results, presented at the International Symposium on Space Techniques for Geodesy, Sopron, Hungary, 1984.

11. Standish, E. M., Orientation of the JPL Ephemeris, DE200/LE200, to the Dynamical Equinox of J2000, *Astron. Astrophys. 114*, 79-106, 1982.

12. Melbourne, W. G., R. Anderle, M. Feissel, R. King, D. McCarthy, D. Smith, B. Tapley and R. Vicente, Project MERIT Standards, *USNO Circular No. 167*, U.S. Naval Observatory, Washington, D. C., Dec. 27, 1983.

13. Chao, C. C., The Tropospheric Calibration Model for Mariner Mars 1971, *Tech. Rep. 32-1587*, 61-76, Jet Propulsion Laboratory, Pasadena, Calif., 1974.

14. Lanyi, G. E., Tropospheric Delay Effects in Radio Interferometry, *TDA Progress Report 42-78*, pp. 152-159, Jet Propulsion Laboratory, Pasadena, Calif., April 1984.

15. Davis, J. and T. Herring, *New Atmospheric Mapping Function*, Harvard College Observatory, Smithsonian Astrophysical Observatory, Technical Memorandum, July 30, 1984.

Table 1. Benchmark source positions

Source	RA, hms			Dec, dms		
T1	0	2	33.76405	0	16	42.2454
T2	6	3	12.33782	29	59	52.9881
T3	12	2	33.12210	59	43	17.7545

Table 2. Benchmark station coordinates, antenna types and offsets

Station	x, km	y, km	z, km	Type	Offset, m
HAYSTACK	1492.407	-4457.267	4296.882	EQU	10
GOLDMARS	-2353.620	-4641.343	3677.053	X-Y	20
CANBERRA	-4446.247	2684.627	-3691.949	X-Y	40
SWEDEN	3370.968	711.466	5349.664	AZEL	2.15
POLE	-3796.424	-104.306	6360.000	AZEL	50

Table 3. Benchmark baselines and lengths

Baseline	Length, km
HAY-GOL	3900
GOL-CAN	10599
GOL-SWE	8014
GOL-POL	5465
CAN-SWE	12114

Table 4. Benchmark observations

Time		Source	Time		Source
82/4/1	0	T1	82/4/1	12	T1
	1	T2		13	T2
	2	T3		14	T3
	3	T1		15	T1
	4	T2		16	T2
	5	T3		17	T3
	6	T1		18	T1
	7	T2		19	T2
	8	T3		20	T3
	9	T1		21	T1
	10	T2		22	T2
	11	T3		23	T3

Table 5. Polar motion and UT1 values for benchmark

Julian Date	Polar Motion, mas		UT1-UTC, msec
	x	y	
2445054	78.0	436.0	–170.0
2445059	90.0	432.0	–182.5
2445064	102.0	428.0	–195.0
2445069	114.0	424.0	–207.5

Table 6. Ocean loading model for benchmark

Component	Station	Amplitude, cm	Phase, deg	Station	Amplitude, cm	Phase, deg
M2	HAYST	0.96	183.2	GOLDM	0.23	351.5
S2		0.26	205.2		0.14	250.3
N2		0.21	165.2		0.12	305.7
K2		0.07	198.4		0.05	276.9
K1		0.39	354.6		0.99	43.8
O1		0.26	355.2		0.62	28.9
P1		0.12	356.8		0.31	43.1
Q1		0.05	358.3		0.12	20.0
MF		0.04	10.5		0.01	295.6
MM		0.02	59.2		0.01	104.9
SSA		0.04	264.0		0.06	74.2

Table 7. Total model delay differences between CALC and MASTERFIT

Type of Comparison	RMS, ps		Maximum, ps	
	All	+ Only	All	+ Only
Raw	73.2	67.4	374.1	237.8
Identical tides, (*a*)	81.8	64.7	374.4	238.7
Solar bending only, (*b*)	75.6	67.0	357.8	244.5
Zero antenna offsets, (*c*)	21.2	26.4	48.7	48.7
(*a*) + (*b*) + (*c*)	38.8	25.5	157.0	50.2

Table 8. Tidal delay and displacement differences between CALC and MASTERFIT

Quantity	RMS difference, ps		Maximum difference, ps		
	Delay	Displacement	Delay	Displacement	
				Local	E-Cent.
Solid tides	7.6	6.9	25.2	22.1	17.2
*K*1 correction	...	0.12	...	...	0.18
Pole tide	0.05	0.05	0.10	0.13	0.10
Ocean loading	0.001	0.001	0.004	0.001	0.001

Appendix

Figure A-1 is a tabulation of "raw" model delays calculated with CALC 6.0 and MFIT.EXE; 333 and their differences. Listed are the observation number, baseline, source, time (ymdh), CALC and MASTERFIT total delays, and their difference (CALC minus MASTERFIT). An asterisk (*) following the source name indicates an observation for which one or both elevation angles are zero or negative. For each baseline, the root mean square difference between CALC and MASTERFIT is calculated for all observations as well as for only those at positive elevation angles.

Observation					Model delay (psec) CALC 6.0	MFIT	DIF.
1	HAY-GOL	T1*	82/4/1	0	-12585612701.157	-12585612711.389	10.232
2	HAY-GOL	T2	82/4/1	1	-3893892543.696	-3893892530.870	-12.827
3	HAY-GOL	T3	82/4/1	2	6627974849.523	6627974868.641	-19.118
4	HAY-GOL	T1*	82/4/1	3	-7085396676.466	-7085396673.550	-2.916
5	HAY-GOL	T2	82/4/1	4	-9509538985.199	-9509538967.877	-17.322
6	HAY-GOL	T3	82/4/1	5	2175372246.348	2175372227.878	18.471
7	HAY-GOL	T1*	82/4/1	6	2590632122.327	2590632144.998	-22.672
8	HAY-GOL	T2*	82/4/1	7	-8916992949.671	-8916992987.427	37.756
9	HAY-GOL	T3	82/4/1	8	-2505749430.424	-2505749424.881	-5.544
10	HAY-GOL	T1*	82/4/1	9	10744906794.568	10744906779.750	14.818
11	HAY-GOL	T2*	82/4/1	10	-2465150182.063	-2465150183.234	1.171
12	HAY-GOL	T3	82/4/1	11	-4659003876.422	-4659003817.997	-58.425
13	HAY-GOL	T1*	82/4/1	12	12575954242.330	12575954240.011	2.319
14	HAY-GOL	T2*	82/4/1	13	6046931392.195	6046931385.644	6.551
15	HAY-GOL	T3	82/4/1	14	-3016481033.448	-3016480965.839	-67.608
16	HAY-GOL	T1	82/4/1	15	7005622254.772	7005622271.324	-16.552
17	HAY-GOL	T2*	82/4/1	16	11607049844.123	11607049889.674	-45.551
18	HAY-GOL	T3	82/4/1	17	1454657529.508	1454657622.209	-92.700
19	HAY-GOL	T1	82/4/1	18	-2686119354.696	-2686119383.565	28.869
20	HAY-GOL	T2	82/4/1	19	10941265333.850	10941265312.359	21.491
21	HAY-GOL	T3	82/4/1	20	6121656289.089	6121656434.588	-145.499
22	HAY-GOL	T1	82/4/1	21	-10792502104.886	-10792502137.607	32.721
23	HAY-GOL	T2	82/4/1	22	4441622393.791	4441622351.781	42.010
24	HAY-GOL	T3	82/4/1	23	8236427202.930	8236427232.913	-29.983
					RMS (no *; all)	54.316	45.023

Observation					Model delay (psec) CALC 6.0	MFIT	DIF.
25	GOL-C	T1	82/4/1	0	-10489285192.723	-10489285177.502	-15.221
26	GOL-C	T2*	82/4/1	1	29273449598.709	29273449578.182	20.527
27	GOL-C	T3*	82/4/1	2	31666616616.733	31666616598.619	18.114
28	GOL-C	T1*	82/4/1	3	-23758218846.926	-23758218840.067	-6.859
29	GOL-C	T2	82/4/1	4	14353178847.841	14353178834.335	13.506
30	GOL-C	T3*	82/4/1	5	33839550962.713	33839550954.473	8.240
31	GOL-C	T1*	82/4/1	6	-22993320249.619	-22993320252.856	3.237
32	GOL-C	T2	82/4/1	7	-1782046094.129	-1782046038.673	-55.456
33	GOL-C	T3*	82/4/1	8	28598744840.469	28598744842.616	-2.147
34	GOL-C	T1*	82/4/1	9	-8644924563.615	-8644924540.795	-22.820
35	GOL-C	T2*	82/4/1	10	-9631363846.549	-9631363822.950	-23.598
36	GOL-C	T3*	82/4/1	11	19030165408.978	19030165470.940	-61.962
37	GOL-C	T1*	82/4/1	12	10838168545.026	10838168579.929	-34.903
38	GOL-C	T2*	82/4/1	13	-4572797071.631	-4572797084.982	13.350
39	GOL-C	T3*	82/4/1	14	10768069531.403	10768069868.862	-337.459
40	GOL-C	T1*	82/4/1	15	23983661117.362	23983661126.302	-8.940
41	GOL-C	T2*	82/4/1	16	10415056242.877	10415056224.272	18.606
42	GOL-C	T3*	82/4/1	17	8677378465.377	8677378510.634	-45.257
43	GOL-C	T1*	82/4/1	18	23051112702.293	23051112723.516	-21.223
44	GOL-C	T2*	82/4/1	19	26506825493.578	26506825517.828	-24.250
45	GOL-C	T3*	82/4/1	20	13989229081.622	13989228994.326	87.296
46	GOL-C	T1	82/4/1	21	8589695859.210	8589695891.955	-32.746
47	GOL-C	T2*	82/4/1	22	34227153040.586	34227153078.053	-37.467
48	GOL-C	T3*	82/4/1	23	23575839561.394	23575839553.200	8.194
					RMS (no *; all)	33.770	75.894

Fig. A-1. "Raw" model delays

Observation					Model delay (psec) CALC 6.0	MFIT	DIF.
49	GOL-SWE	T1*	82/4/1	0	16185720822.098	16185720828.309	-6.211
50	GOL-SWE	T2	82/4/1	1	17993984333.845	17993984317.336	16.509
51	GOL-SWE	T3	82/4/1	2	-6704573201.099	-6704573227.812	26.714
52	GOL-SWE	T1*	82/4/1	3	-3122544321.856	-3122544319.901	-1.955
53	GOL-SWE	T2*	82/4/1	4	18237985299.639	18237985268.271	31.368
54	GOL-SWE	T3	82/4/1	5	3065860092.861	3065860066.385	26.476
55	GOL-SWE	T1*	82/4/1	6	-20602185597.935	-20602185597.695	-0.240
56	GOL-SWE	T2	82/4/1	7	6100368835.672	6100368799.121	36.551
57	GOL-SWE	T3	82/4/1	8	8191086555.686	8191086515.249	40.436
58	GOL-SWE	T1*	82/4/1	9	-25960663261.192	-25960663247.461	-13.731
59	GOL-SWE	T2*	82/4/1	10	-11271861472.590	-11271861505.598	33.008
60	GOL-SWE	T3	82/4/1	11	5653219083.324	5653219027.937	55.386
61	GOL-SWE	T1*	82/4/1	12	-16042735574.646	-16042735569.644	-5.003
62	GOL-SWE	T2*	82/4/1	13	-23649410272.859	-23649410314.626	41.767
63	GOL-SWE	T3	82/4/1	14	-3053364888.251	-3053364924.789	36.538
64	GOL-SWE	T1	82/4/1	15	3311626032.342	3311626024.955	7.387
65	GOL-SWE	T2*	82/4/1	16	-23743982434.421	-23743982452.398	17.977
66	GOL-SWE	T3	82/4/1	17	-12801967736.361	-12801967783.033	46.672
67	GOL-SWE	T1*	82/4/1	18	20705974196.957	20705974220.002	-23.045
68	GOL-SWE	T2	82/4/1	19	-11499896861.510	-11499896828.546	-32.964
69	GOL-SWE	T3	82/4/1	20	-17852311291.384	-17852311418.687	127.303
70	GOL-SWE	T1*	82/4/1	21	25897978015.240	25897978051.196	-35.956
71	GOL-SWE	T2	82/4/1	22	5873154425.261	5873154471.908	-46.647
72	GOL-SWE	T3	82/4/1	23	-15230584157.899	-15230584183.491	25.592
					RMS (no *; all)	49.160	39.601

Observation					Model delay (psec) CALC 6.0	MFIT	DIF.
73	GOL-P	T1	82/4/1	0	5340718523.284	5340718285.470	237.814
74	GOL-P	T2	82/4/1	1	10213082801.243	10213082739.583	61.660
75	GOL-P	T3	82/4/1	2	-6011503170.623	-6011503231.485	60.862
76	GOL-P	T1*	82/4/1	3	-7663353656.411	-7663353892.195	235.784
77	GOL-P	T2	82/4/1	4	6522352926.267	6522352851.542	74.725
78	GOL-P	T3	82/4/1	5	-591502606.599	-591502666.631	60.032
79	GOL-P	T1*	82/4/1	6	-16171214562.317	-16171214649.323	87.006
80	GOL-P	T2	82/4/1	7	-3643744283.646	-3643744350.026	66.380
81	GOL-P	T3	82/4/1	8	621339818.869	621339750.440	68.430
82	GOL-P	T1*	82/4/1	9	-15173163478.887	-15173163572.408	93.521
83	GOL-P	T2*	82/4/1	10	-14299105695.405	-14299105764.133	68.728
84	GOL-P	T3	82/4/1	11	-3087131113.445	-3087131192.689	79.244
85	GOL-P	T1*	82/4/1	12	-5256757234.665	-5256887060.910	129826.244
86	GOL-P	T2*	82/4/1	13	-19169522762.562	-19169522843.099	80.537
87	GOL-P	T3	82/4/1	14	-9533257528.390	-9533257592.090	63.700
88	GOL-P	T1	82/4/1	15	7738596413.005	7738596312.038	100.968
89	GOL-P	T2*	82/4/1	16	-15387123092.829	-15387123162.407	69.579
90	GOL-P	T3	82/4/1	17	-14921370529.279	-14921370612.200	82.921
91	GOL-P	T1	82/4/1	18	16161150625.774	16161150583.615	42.159
92	GOL-P	T2	82/4/1	19	-5179119029.039	-5179119053.382	24.343
93	GOL-P	T3	82/4/1	20	-16078778204.958	-16078778369.709	164.751
94	GOL-P	T1	82/4/1	21	15051330462.976	15051330421.856	41.119
95	GOL-P	T2	82/4/1	22	5443695609.533	5443695604.304	5.229
96	GOL-P	T3	82/4/1	23	-12323948800.114	-12323948858.500	58.386
					RMS (no *; all)	92.159	100.509

Fig. A-1 (contd)

Observation						Model delay (psec) CALC 6.0	MFIT	DIF.
97	C	-SWE	T1*	82/4/1	0	26675008002.348	26675007993.396	8.952
98	C	-SWE	T2*	82/4/1	1	-11279514315.827	-11279514311.919	-3.908
99	C	-SWE	T3*	82/4/1	2	-38371202775.555	-38371202784.196	8.641
100	C	-SWE	T1*	82/4/1	3	20635644839.992	20635644835.129	4.864
101	C	-SWE	T2*	82/4/1	4	3884792300.511	3884792282.556	17.956
102	C	-SWE	T3*	82/4/1	5	-30773722146.810	-30773722165.147	18.337
103	C	-SWE	T1	82/4/1	6	2391089752.881	2391089756.316	-3.435
104	C	-SWE	T2	82/4/1	7	7882414423.181	7882414331.183	91.998
105	C	-SWE	T3*	82/4/1	8	-20407683883.853	-20407683926.588	42.734
106	C	-SWE	T1*	82/4/1	9	-17315751717.739	-17315751726.858	9.119
107	C	-SWE	T2	82/4/1	10	-1640510985.784	-1640511042.366	56.582
108	C	-SWE	T3*	82/4/1	11	-13376952774.638	-13376952892.106	117.468
109	C	-SWE	T1*	82/4/1	12	-26880902248.027	-26880902277.886	29.859
110	C	-SWE	T2*	82/4/1	13	-19076620852.110	-19076620880.523	28.413
111	C	-SWE	T3*	82/4/1	14	-13821429930.569	-13821430304.624	374.054
112	C	-SWE	T1*	82/4/1	15	-20672065362.659	-20672065378.922	16.263
113	C	-SWE	T2*	82/4/1	16	-34159028532.921	-34159028532.285	-0.636
114	C	-SWE	T3*	82/4/1	17	-21479338156.173	-21479338248.132	91.959
115	C	-SWE	T1*	82/4/1	18	-2345183551.590	-2345183549.819	-1.771
116	C	-SWE	T2*	82/4/1	19	-38006730272.234	-38006730263.484	-8.751
117	C	-SWE	T3*	82/4/1	20	-31841527901.186	-31841527941.220	40.035
118	C	-SWE	T1*	82/4/1	21	17308269312.116	17308269315.262	-3.146
119	C	-SWE	T2*	82/4/1	22	-28354046379.223	-28354046370.044	-9.180
120	C	-SWE	T3*	82/4/1	23	-38806415917.829	-38806415935.253	17.424
						RMS (no *; all)	62.389	86.760
						RMST (no *; all)	67.410	73.194
						MAX (no *; all)	237.814	374.054

Fig. A-1 (contd)