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Session III of the VLBI/Laser Intercomparison Task of the NASA Crustal Dynamics Project

Henry Fliegel

November 1, 1981

NASA
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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ABSTRACT

Baseline vector measurements are reported for a line crossing most of the state of California from Quincy to Mt. Otay near the Mexican border. They were obtained as Session III of the VLBI/Laser Intercomparison Task of the NASA Crustal Dynamics Project. The purpose of the task was to compare three space geodetic techniques:

Very Long Baseline Interferometry
Satellite Laser Ranging
Doppler Satellite Tracking

1. INTRODUCTION

This document is the final report of Session III of the VLBI/Laser Intercomparison task of the NASA Crustal Dynamics Project. It briefly describes the validation and intercomparison experiments performed in California in 1979 at four common sites by ARIES VLBI (Very Long Baseline Interferometry), MOBLAS SLR (MOBile LASer Satellite Laser Ranging), and doppler satellite tracking. The objectives of the VLBI/Laser Intercomparison task are

- to assess VLBI and laser systems performance
- to identify potential problems in the application of VLBI or laser systems by NASA or other government agencies
- to assist systems development managers to resolve any such problems
- to demonstrate the readiness of both VLBI and laser systems for geodetic applications.

Four sites were chosen for the 1979 (Session III) experiments described in this report (see Figure 1), all in the state of California. Two sites, one near the town of Quincy in the northern Sierras and the other by the summit of Mt. Otay close to the U.S.-Mexican border, had been chosen as the MOBLAS occupation sites for SAFE (the San Andreas Fault Experiment) conducted as part of the NASA Crustal Dynamics Project. These two sites were selected for the VLBI-Laser Intercomparison task in order to maintain continuity in the series of MOBLAS measurements. Two other sites, OVRO (Owens Valley Radio Observatory) and DSS 13 (Deep Space Station 13, also called Venus), were selected because they were between Quincy and Otay and hence the logical base stations to use for VLBI experiments in California, and also to maintain continuity in the ARIES (Astronomical Radio Interferometric Earth Surveying) series of experiments conducted by the NASA Crustal Dynamics Project.

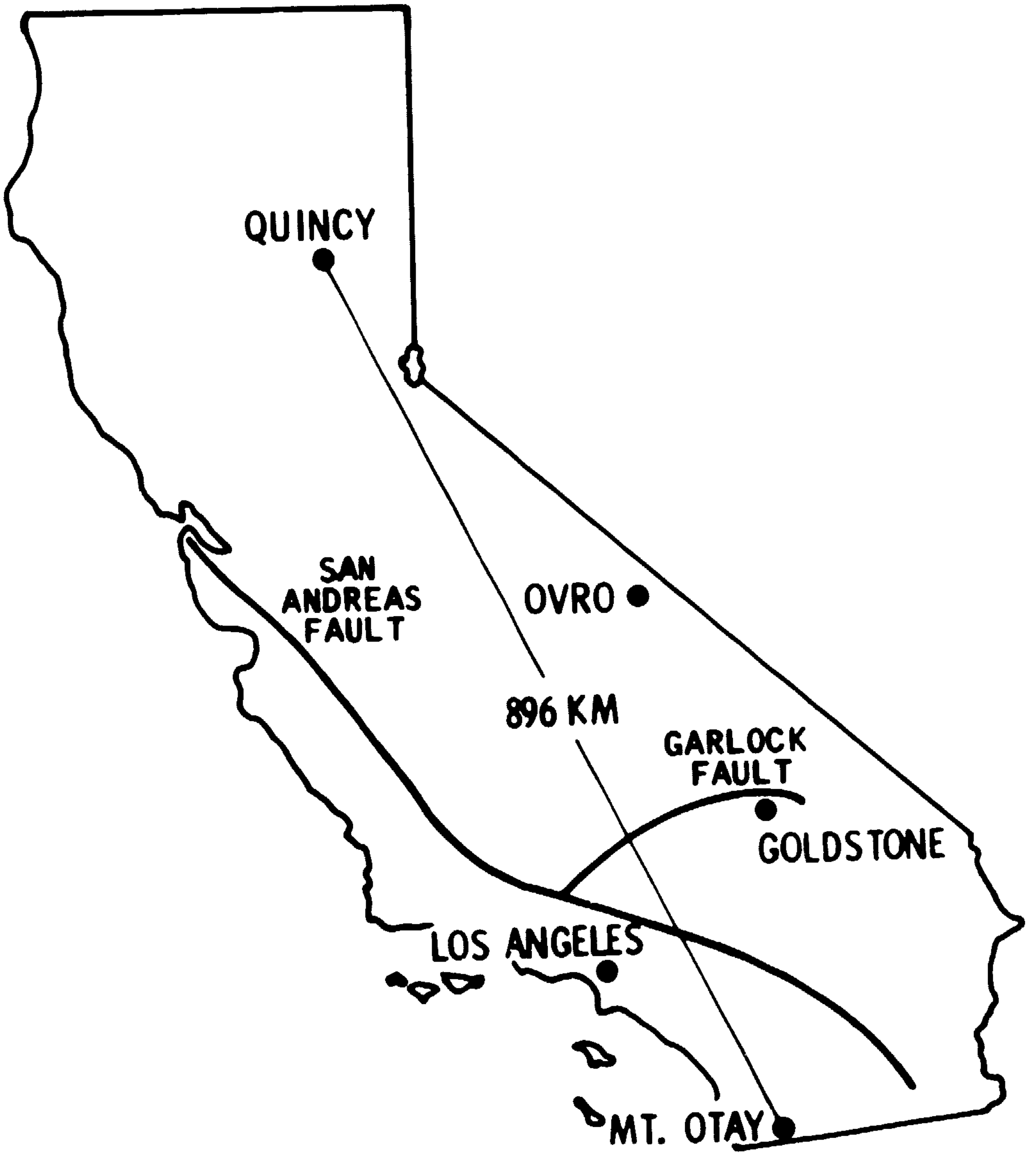


Fig. 1. VLBI/Laser Intercomparison Project
Baseline for Session III

The SLR (MOBLAS) data acquisition was timed to support concurrently the VLBI-Laser Intercomparison Task and the SAFE experiment. Details of MOBLAS operational procedure are described in NASA STDN 502.33 (Network Procedures for Laser Systems) dated April 1978.

The VLBI measurements were performed by the ARIES 9-meter antenna, originally an Army Signal Corps satellite communications antenna, which had been reconditioned at JPL and used since 1973 in an extensive series of geodetic measurements in southern California. It had never previously been used to measure lines as long as that from Quincy to Otay.

Special doppler satellite observations were made at the intercomparison sites by the National Geodetic Survey.

2. ARIES

2.1 System Configuration

The ARIES 9-meter system operated at the intercomparison site near Quincy from 9 to 12 May 1979, and at the site on Mt. Otay from 11 to 15 July 1979. A sample schedule (for Quincy) is included as Appendix 1 of this report. No emergencies or highly unusual incidents were reported during data acquisition. The ARIES 9-meter was operated simultaneously with DSS 13 at Goldstone, California, and with the 40-meter antenna at Owens Valley Radio Observatory (OVRO). DSS 13 was then configured as a 26-meter antenna with the following data acquisition parameters:

- S-band
- two channel bandwidth synthesis
- channel separation of 40 MHz
- channel frequencies of 2270-2272 and 2310-2312 MHz
- recording rate of 4 megabits/second.

The OVRO station acquired S- and X-band data simultaneously. The S-band parameterization was (of course) the same as that of DSS 13, just given. The X-band data acquisition parameters were

- two channel bandwidth synthesis
- channel separation of 80 MHz
- channel frequencies at X-band 8410-8412 and 8490-8492 MHz.
- recording rate of 4 megabits/second.

Hydrogen masers were operating at both these base stations. Water vapor radiometers were deployed at all sites.

2.2 The ARIES Data Acquisition

Four experiments were performed according to the schedules given in Appendices 1 and 2, two with ARIES at Quincy and two at Otay. They were designated 79G (9 and 10 May 1979, at Quincy), 79H (11 and 12 May 1979, at Quincy), 79K (11 and 12 July 1979, at Otay), and 79L (14 and 15 July 1979, at Otay).

The experimental results are summarized as follows:

79G(S) - Successful on all 3 baselines. Closure was less than 10 cm on all components.

79G(X) - The number of successful scans was very small, due to SNR problems with ARIES at X-band at that time. (Sources had not yet been identified which would be strong at X-band, and signal strength was very weak.)

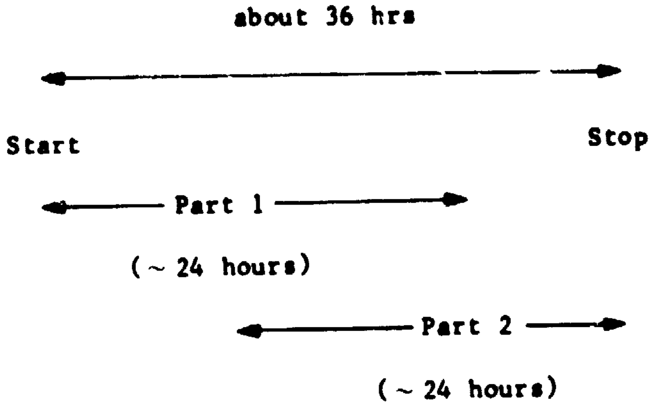
79H(S) - Maser failure at OVRO. Data was not processed beyond phase tracking on any baselines.

H(X) - Same troubles as G(X), above.

79K(S) - All 3 baselines processed through ARIES program SRIFIT, but solutions were very sensitive to clock parameterization (see below), and post-fit residual scatter was exceptionally large. It was decided not to include baselines in "final baseline" BNCHMRK files.

79K(X) - Residual scatter not as bad as K(S), but, due to the relatively insensitive ARIES X-band receiver, the successful scan yield was very low. Furthermore, this baseline did not agree well in components or length with OTAY/OVRO from K(S). The ARIES team decided to disregard the results.

79L(S) - This experiment was extended from the originally scheduled 24 hours to 36 hours due to a hardware problem at one of the stations. There seems to be no existing record of the nature, degree, or location of the hardware troubles. The ARIES team processed all 36 hours of data from each baseline through the SRIFIT fitting program. Since program constraints forced the team to deal with not more than about 24 hours of data in each run of the fitting programs, the ARIES team divided the data in this manner:



Notice that Part 1 and Part 2, therefore, are about 50% correlated.

In sum, the usable results of the ARIES observations are entirely from experiments 79G (S-band) and 79L (S- and X-band).

2.3 The Reduction of the ARIES Data

The most crucial single factor in the reduction of the ARIES data is the method of estimating the behavior of the clocks used in the experiments. The procedure used in early 1980, when the data reported here were reduced, was as follows. Using all the delay data of a given experiment and for a single antenna pair, a single solution was made for the three components of the baseline vector, an offset between the clocks at the two antennas, and a clock rate. Residuals were calculated for each scan -- that is, for each ten or fifteen minute observation of a single celestial source -- and scans giving what seemed to be unreasonably high residuals were discarded. Then a sequence of straight line segments was fitted by least squares thru the remaining delay residuals, each residual representing a single scan. This sequence of straight line segments was believed to represent the "clock breaks" -- that is, the relative instability of the two frequency standards (or their distribution systems) at the two antennas. Some control was exercised on the estimation of the times of these clock breaks by requiring, during 3-station experiments, that a break be presumed to occur at the same time on two baselines -- which must be the case if a real discontinuity occurred in the frequency delivered at the station common to those two baselines.

The number of scans retained and the number of parameters introduced in the ARIES solutions are summarized in Table 1.

Table 1. Reduction Parameters: VLBI Data

Experiment	Duration of Experiment (hours)	Number of Scans Retained	Number of Clock Breaks Introduced
79G: (S band)			
DSS 13 to Quincy	24.48	72 of 92	11
OVRO to Quincy	25.45	55 of 80	9
DSS 13 to OVRO	25.47	73 of 88	8
79L: (S band)			
DSS 13 to Otay (Part 1)	22.35	57 of 77	14
DSS 13 to Otay (Part 2)	23.16	50 of 73	11
OVRO to Otay (Part 1)	22.56	55 of 78	14
OVRO to Otay (Part 2)	23.16	59 of 82	13
79L: (X band)			
OVRO to Otay	25.47	62 of 90	4

The procedure used for estimating the number and the times of the presumed discontinuities in frequency of the clock(s) must be examined critically in any evaluation of the ARIES results, for two reasons. First, the baseline solutions themselves are affected by the assumptions made. Second, the formal estimates of error (standard deviations) of the baseline components, printed in the computer output, do not reflect the uncertainty in the assumed clock break behavior. In this report, the final baseline solutions derived by the ARIES team in early 1980 have been retained as being the best estimates available, but the errors have been reestimated in Section 2.5, below.

2.4 The Astronomical Parameters Used in the Solutions

At the time when the Session III ARIES data were reduced (early 1980), the logic of coordinate transformations employing astronomical parameters was contained in an ARIES computer subroutine called MDLGET. (This code has since been replaced by the software employed for Deep Space Network intercontinental VLBI.) As part of the ARIES effort, checks were made of all the astronomical rotations performed in MDLGET, using output from the lunar laser ranging program LPRED and calculations based on the American Ephemeris and Nautical Almanac and its Explanatory Supplement. Polar motion computations were also checked using test sample calculations. No mistakes were found, and the largest astronomical effects omitted in the code do not exceed ".03. The largest possible effect on the Quincy-Otay baseline would therefore be 13 cm. in baseline orientation, if all error sources had their maximum value and were correlated. The expected value of the error due to these modelling approximations is 4 cm. or less in orientation, less than 1 cm. in length.

To calculate the apparent position of a celestial object by the classical algorithms, in the frame of reference of a terrestrial observer, requires the calculation of six rotations of coordinates:

four of the Earth,

1) precession
2) nutation
3) time
4) polar motion

and two of the astronomical object,

5) annual aberration
6) diurnal aberration

To be sure, the above classification is somewhat arbitrary. Aberration (5 and 6) is conventionally treated as an angular displacement of the celestial object, but in VLBI it is handled via the calculation of relativistic time delay of the signal between the two ends of the baseline. Precession and nutation conventionally are thrown into the calculation of the celestial object's apparent place, and such is the procedure of ARIES program MDLGET. But for the purposes of this report, the above outline will be followed.

LPRED, used as an independent check for the purpose of validation, calculates only the first four rotations, dealing with the Earth. MDLGET rotates the vector baseline between the stations by time and polar motion (3 and 4), and applies precession, aberration, and nutation (1, 2, 5, and 6) to the celestial object. Since the two programs are logically quite different, it was possible directly to compare the numerical output only with regard to precession and nutation (1 and 2). The other rotations were checked by pocket calculator and against the American Ephemeris and Nautical Almanac via a small Fortran program called PTEST.

Two effects which are not rotations of coordinates are important to ARIES: atmospheric time delay (including especially the ionosphere); and accuracy of source location information, including effects of source structure and changes of source structure.

The six possible astronomical rotations itemized above appear in MDLGET, and were checked as follows:

1) and 2) precession and nutation:

The baseline vector ROUT from LPRED was converted to spherical coordinates and input to MDLGET as a 1950.0 source location, and the apparent place calculated from MDLGET was compared to REE from LPRED.

3) <u>true sidereal time</u>:

The Greenwich true sidereal time at the beginning of the observing interval is printed by MDLGET as AO. This was checked against a hand calculation from the tables of the <u>American Ephemeris</u>, and also against THETA from LPRED, bearing in mind that MDLGET truncates the starting time to the nearest second of UT, and LPRED does not.

4) <u>polar motion</u>:

Since polar motion does not appear in MDLGET, but only in the final ARIES fitting program, we proceeded as follows. Three sets of instantaneous station coordinates were taken from ARIES reductions on three different dates. Remembering that station coordinates are specified in a right-handed coordinate system, but that BIH x and y coordinates of the pole are left-handed (that is, y positive toward the 90th meridian <u>west</u> of Greenwich), we have the following coordinate transformations:

$$X = X_o - Z_o\, x,$$
$$Y = Y_o + Z_o\, y,$$
$$Z = Z_o + xX_o - yY_o,$$

where (X_o, Y_o, Z_o) are station coordinates with respect to the CIO,

(X, Y, Z) are station coordinates with respect to the Earth's spin axis,

(x, y) are BIH polar coordinates.

Alternately, the transformation can be performed in spherical coordinates by the following equations, which are adapted from those published in the BIH Annual Report for 1968 by making the signs compatible for east station longitudes:

$$x \cos \lambda - y \sin \lambda = \phi - \phi_{cio},$$

$$x \tan \phi \sin \lambda + y \tan \phi \cos \lambda = \lambda - \lambda_{cio},$$

where ϕ = station latitude,

λ = station east longitude

cio (subscript) denotes station coordinates with respect to the Conventional International Origin,

= the geographic north pole

(x,y) are BIH polar coordinates, as before.

The transformations were performed both ways as a check, and then used to verify ARIES output.

5) annual aberration:

Apparent places in the VOS MODEL test output supplied from VLBI software were checked against calculations made according to the Explanatory Supplement to the Ephemerides, pp. 151-165, using the Besselian day numbers in the American Ephemeris, for six sources.

6) diurnal aberrations:

Since this is performed relativistically in the ARIES program, an investigation was made of how the ARIES formulation compares with the classical treatment.

By special relativity, to the second order in v/c,

$$\sin(\theta - \theta_o) = -\frac{v}{c}\sin\theta + \frac{v^2}{4c^2}\sin 2\theta,$$

where v is the observer's velocity;

θ is the angle between the source vector and the observer's velocity vector, in the reference frame;

θ_o is the apparent angle, similarly defined;

c is the speed of light.

From classical theory, the formula for aberration is

$$\sin(\theta - \theta_o) = -\frac{v}{c}\sin\theta,$$

so that the difference between the classical and relativistic formula is the term

$$\frac{v^2}{4c^2}\sin 2\theta,$$

the amplitude of which is about ."0005 for the annual aberration, and quite negligible for the diurnal aberration.

However, there is one important point which must be recognized when comparing the output of VLBI code with either relativistic or classical theory. In VLBI, the term

$$\frac{\vec{B}\cdot\vec{v}}{c^2}$$

is calculated by equating $\vec{v}$ to the Earth's orbital velocity, and neglecting the contribution of the Earth's rotation. This involves no error, because $\vec{B}\cdot\vec{V}_{\mathrm{rotational}}$ is very nearly a constant, and can be and is absorbed into the solution for the clock offset between the two stations. However, this means that, after calculating the time delay due to diurnal aberration by the classical formula, one must subtract the quantity $\vec{B} \cdot \vec{v}/c^2$ due to the Earth's rotation in order to obtain a number which can be compared to the VLBI result. Logically, the VLBI procedure is analogous to the conventional astronomical practice of discarding that part of the annual aberration that corresponds to the non-circular part of the Earth's velocity -- a practice that has caused no small grief to users.

By way of comparison, the MIT procedure is described, e.g., by Counselman in the article "Radio Astrometry," Annual Review of Astronomy and Astrophysics, vol 14 (1976), pp 197-214. They use the same approximations that JPL does -- that is, from Counselman's equation 5 (p205), if we difference his quantity T_i (t) between the two observing stations, we obtain the measured time delay; but his use of $\vec{R}$ (Earth's orbital velocity) as the velocity of the observer effectively throws the term due to Earth rotational velocity into the clock offset, as with JPL. (Notice that Counselman's Equation 4 is essentially a series expansion -- to the order v^2/c^2, of the basic expression

$$\frac{\vec{B} \cdot \vec{s}}{c + v \cos\theta} \quad).$$

The conclusions from the study of ARIES modelling accuracy were as follows. In the ARIES code which dealt with astronomical coordinates, the following seem to have been the principal sources of error, roughly in the order of decreasing size.

1. The speed of light was taken to be 299792.5 km/sec; the officially defined value is 299792.458 km/sec. This is not strictly a source of error, since it was known and has been corrected in data disseminated by the National Geodetic Survey and in this report.

2. Not calculating planetary perturbations on the Earth's velocity can cost up to ".03, although the mean square error is more like ".003.
3. Omission of the effects, broadly related to nutation, due to solid Earth tides, the non-rigidity of the Earth, ocean tidal loading, etc., contribute a messy package of error totalling probably about ".005 to ".010.
4. Not calculating lunar perturbations on the Earth's velocity produced an error having an amplitude of ".0086.
5. Other effects (such as relativistic aberration) were ".0005 or smaller.

The question was also raised: how do errors in estimating rotational parameters -- for example, UT1 and polar motion -- enter into baseline length estimates for the Quincy-Mt. Otay ARIES experiment? At first glance, the answer might seem to be that rotational errors do not affect baseline lengths. However, rotational errors do enter the problem, since the Quincy-Mt. Otay line was measured in two segments -- e.g., Quincy-OVRO + OVRO-Mt. Otay -- and a rotation of one segment with respect to the other will affect the magnitude of their vector sum. The most important components of error in any presently available source of UT1 and polar motion are expected to be of annual and semi-annual periodicity. Since VLBI observations were separated by about 60 days, the UT1 and polar motion errors were essentially uncorrelated between the Quincy and Mt. Otay experiments.

The angle between the line Quincy-OVRO to the line Quincy-Otay is 12°.8; that between the line OVRO-Otay and Quincy-Mt. Otay is 9°.2. The standard deviations to be expected in the best currently available earth rotation data are 30 cm in X, 20 cm in Y, and 1.5 milliseconds in UT1. The total length of the error vector of the Quincy-OVRO segment is therefore expected to be 4.2 cm;

that of OVRO-Otay, 5.8 cm. The effect on the total baseline length is calculated to be

$$5.8 \sin 9\overset{\circ}{.}2 + 4.2 \sin 12\overset{\circ}{.}8 = 1.8 \text{ cm.}$$

A similar calculation using the DSS 13 antenna gives

$$7.0 \sin 10\overset{\circ}{.}7 + 3.2 \sin 34\overset{\circ}{.}4 = 3.1 \text{ cm.}$$

2.5 Estimates of the Accuracy of the ARIES Data

We have two estimators of the precision of the ARIES S-band data which are independent of the estimates of formal error.

In the 79G and 79L experiments, three antennas operated simultaneously: ARIES, DSS 13, and OVRO. Two independent estimates can be formed of the Quincy-Otay baseline vector: one using ARIES-DSS 13, and a second using ARIES-OVRO. The differences are:

Table 2

Quincy minus Otay: OVRO Estimate minus DSS 13 Estimate

ΔX	ΔY	ΔZ	ΔL (baseline length)
+.075	+.184	-.027	+.096

The 79L experiment was divided into two parts (see Section 2.2, above). The differences are

Table 3

Experiment 79L: Difference Between Parts 1 and 2

	ΔX	ΔY	ΔZ	ΔL (baseline length)
using DSS 13	.050	.001	.086	.059
using OVRO	.144	.005	.104	.061

It must be remembered that Parts 1 and 2 have a 50% overlap (see Section 2.2); if they had been independent, the differences of Table 3 would presumably increase by $\sqrt{2}$.

Ignoring any possible scaling of errors with baseline length, we can form a rough estimate of the ARIES precision of a single experiment from the data of Tables 1 and 2. The root mean square error of a single component is about 11 cm, and the expected error in baseline length is about 9 cm.

Sources of error which are expected to scale with baseline length are those which would not appear in the differences presented in Tables 1 and 2, because they are roughly the same for different parts of an experiment: ionosphere, the effects of UT1 and polar motion, and modelling error. From the study described in Section 2.4, we estimate the effect of modelling error to be about 4 cm on the individual components of the Quincy-Otay vector, and negligible for the length. Combined UT1 and polar motion error should not exceed 6 cm on any component, and should be less than 2 cm in baseline length.

An upper limit to the effect of the ionosphere on the OVRO minus Otay line can be estimated as the difference between the S- and X-band results of 79L:

Differences Between S-band and X-band: OVRO minus Otay

ΔX	ΔY	ΔZ	ΔL (baseline length)
.24	.17	.10	.17

Independently of the above, estimates of the effect of the ionosphere on the Quincy/Otay baseline length were made using Faraday rotation values of electron densities over southern California; the corrections are -.285 m.

using OVRO and -.291 m. using DSS 13. The correction for the OVRO/Otay segment alone is .16 meters, in good agreement with the S versus X-band result given above. In Table 7, we show the effect of applying these corrections to the S-band ARIES data.

From the above discussion, we tentatively conclude that the accuracy of the corrected ARIES Quincy/Otay determination was roughly 10 to 15 cm in individual components, and about 9 to 12 cm (or about 1 part in 10^7) in baseline length.

3. DOPPLER DETERMINATIONS OF THE QUINCY/OTAY BASELINE

The National Geodetic Survey established doppler satellite stations using Geoceivers at all four Session III Intercomparison sites. The complete listing of doppler station solutions, including those used in the calculations of Section 6 of this report, is included as Appendix 2. A paper describing the NGS doppler data reduction technique was presented at the 1981 Spring Annual Meeting of the Americal Geophysical Union, and the pages relevant to the present report are included as Appendix 3.

4. THE SATELLITE LASER RANGING EFFORT DURING SESSION III

During the time period March 1979 through May 1979 Goddard Space Flight Center Satellite Laser Ranging (SLR) systems were located on Otay Mt., near San Diego, CA and at Quincy, CA for the purpose of determining the baseline distance between these two sites. The satellite used for this analysis was the LAGEOS spacecraft and the amount of data collected is given in Table 4. Parameters used in the analysis for the Earth and LAGEOS Satellite orbits are given in Table 5. Analysis of these data, using three 1-month orbital arcs statistically averaged over a 3-month period yields the station position locations given in Table 6. The resultant baseline between the Otay Mt. and Quincy survey points is 896274.315 ± 0.10 meters. The vector values are summarized in Table 7 as MOBLAS Set II.

A presumably more accurate set of values, based on all 1979 LAGEOS data from Quincy and Otay, is presented in Table 7 as MOBLAS (Set I).

Table 4. LAGEOS Data Collected

Location	Site No.	No. of LAGEOS Passes	No. of Data Points
Otay Mt., CA	7062	33	9491
Quincy, CA	7051	13	4840

Table 5. Earth and LAGEOS Satellite Parameters

GM	$398600.43 \times 10^9 m^3/sec^2$
a_e	6378144.11 m
k_2	0.2857
2	1.87254 degs
Solar radiation pressure coefficient	1.1729
Average alongtrack (in orbit) acceleration	$-5.59 \times 10^{-12} m/sec^2$
Gravity field	GME 10 (modified)
LAGEOS mass	411.0 kg
LAGEOS cross-sectional area	0.28274 m
Velocity of Light	299,792,458 m/sec

Polar motion solved for

LAGEOS orbit elements

$a = 12265.82$ km

$e = 0.00428$

$i = 109.835$ degrees

5. THE GROUND SURVEYS

Each team -- ARIES, doppler, and MOBLAS -- placed a reference mask on the ground at each site, and was responsible for referring the data obtained by their equipment to that mark. Ties between those marks at each site were made by the National Geodetic Survey under the supervision of Mr. L.D. Hothem. The contribution of ground survey error to the Session III Intercomparison results is believed to be negligible. National Geodetic Survey determinations of vector baseline translations at all intercomparison sites are included in Appendix 5.

6. HISTORY OF REPORTING SESSION III RESULTS

A preliminary report of the ARIES Quincy/Otay results was made on 27 November 1979 at a telephone conference between JPL and Goddard Space Flight Center. The numbers reported were as follows (all distances in meters):

Table 6. ARIES Quincy/Mt. Otay Vectors (Preliminary Results)*

	X	Y	Z
OVRO as Base Station			
Otay - OVRO	-19 227.96 ± 0.12	-321 408.43 ± 0.07	-421 330.08 ± 0.08
OVRO - Quincy	107 382.98 ± 0.06	-279 537.62 ± 0.05	-237 787.78 ± 0.06
Otay - Quincy	88 155.02 ± 0.13	-600 946.05 ± 0.08	-659 117.86 ± 0.10
DSS 13 as Base Station			
Otay - DSS 13	-77 699.50 ± 0.06	-144 280.76 ± 0.06	-243 683.76 + 0.08
DSS 13 - Quincy	165 854.56 ± 0.10	-456 665.10 ± 0.07	-415 434.14 ± 0.08
Otay - Quincy	88 155.06 ± 0.12	-600 945.86 ± 0.10	-659 117.90 ± 0.11

Quincy - Mt. Otay Length:

Via OVRO	896 294.49 ± 0.08
Via DSS 13	-896 294.40 ± 0.10
Difference	0.09 ± 0.13 M

*Measured between intersection of axes

At the request of the National Geodetic Survey (NGS), a letter was sent from Henry Fliegel of JPL to L.D. Hothem of NGS, dated 9 June 1980, stating that "the best available VLBI results for the Quincy/Mt. Otay baseline are still those of the 'Preliminary Results' viewgraphs" [given above as Table 6]. However, immediately after this letter was sent, the ARIES team reported that the original computer runs had been examined and a mistake had been discovered: the ARIES position at Quincy, which had been reported as "measured between intersection of axes," had in fact been reduced to the survey point below the antenna, and so was inconsistent with the result reported for Otay. Accordingly, a corrected set of results was sent to the NGS in a letter dated 12 June 1980, included in the present report as Appendix 5.

In the process of preparing this report, a further mistake was discovered. A change had been made to the ARIES code since the certification described in Section 2.4. The UT1 correction was made only approximately in subroutine MDLGET, and the final UT1 correction was made, together with the polar motion correction, in a subsequent link called BNCHMRK. In BNCHMRK, the UT1 correction was applied with the wrong sign. Also, certain UT1 and polar motion corrections which were labeled "BIH Circular D smoothed" were in fact taken from the BIH Rapid Service. When these mistakes are corrected, we pass from the values of Appendix 5 to those of Section 7 (below).

No SLR baseline solutions were reported in the teleconference of 27 November 1979. In the Space System Intercomparison Meeting held 16 June 1980 at Goddard Space Flight Center (GSFC), L.D. Hothem of NGS reported the comparison between MOBLAS SLR and ARIES VLBI baseline lengths as follows:

$\mathrm{SLR}_{1979} - \mathrm{ARIES}_{\mathrm{OVRO}}$	+0.23 meters
$\mathrm{SLR}_{1979} - \mathrm{ARIES}_{\mathrm{DSS\ 13}}$	+0.33 meters

The ARIES values used were those of Appendix 5. The MOBLAS values were not given directly, but SLR-ARIES values just given imply that the MOBLAS baseline value was then being reported as 896 295.19 meters, about 85 to 90 cm longer than the values reported now.

Two sets of results of MOBLAS data were supplied by Ronald Kolenkiewicz of GSFC for inclusion in the present document. Set I, based on all 1979 ranging data taken at Quincy and Otay, was supplied on 27 August 1981, and Set II, based exclusively on data taken during the intercomparison campaign, on 3 September 1981.

7. FINAL INTERCOMPARISON OF SESSION III RESULTS

The final results of the Session III VLBI-Laser Intercomparison effort are presented in Table 7.

The difference between the VLBI and MOBLAS baseline length results are well within their estimated uncertainties; the two techniques agree to better than 15 centimeters.

It would be very desirable to remeasure the Quincy-Otay baseline by both VLBI and laser techniques. Since the rate of change of the length of this baseline reported by the satellite laser technique is 9 cm per year, and since the laser and VLBI techniques agree to about the same value, useful results could be obtained by reoccupying the sites at two year intervals.

Table 7. Final Results From Session III (All Values in Meters)
(± one standard deviation: formal error)

I. ARIES Experiments: (assuming c = 299 792.5 km/sec)

	X	Y	Z
79 G:			
Quincy/DSS 13	165 857.443 ± .045	-456 660.697 ± .059	-415 438.337 ± .071
Quincy/OVRO	107 385.752 ± .028	-279 533.244 ± .037	-237 791.991 ± .050
OVRO/DSS 13	58 471.670 ± .028	-177 127.546 ± .040	-177 646.396 ± .042
(closure error)	-.021	-.093	-.050
79 L:			
S-band			
Otay/DSS 13			
(Part 1)	+77 699.465 ± .059	+144 280.796 ± .072	+24 683.721 ± .094
(Part 2)	.415 ± .046	.797 ± .064	.807 ± .076

Table 7. Final Results From Session III (All Values in Meters) (Continued)

	X	Y	Z
Otay/OVRO			
(Part 1)	+19 227.752 ± .053	+321 408.435 ± .051	+421 330.122 ± .073
(Part 2)	.896 ± .060	.430 ± .062	.042 ± .085
OVRO/DSS 13			
(Part 1)	+58 471.596 ± .028	-177 127.638 ± .040	-177 646.317 ± .042
(Part 2)	.546	.777	.144
79 L:			
X-band			
Otay/OVRO	+19 228.065 ± .015	+321 408.266 ± .022	+421 329.986 ± .026

II. ARIES Mean Value: Otay/Quincy

	X	Y	Z	L (baseline length)
between ARIES intersections of axes	-88 157.966	+600 941.585	+659 122.088	896 294.897
transferred to MOBLAS reference marks	-88 067.494	+600 906.125	+659 138.901	896 274.594
corrected to standard speed of light	-88 067.481	+600 906.041	+659 138.809	896 274.467
corrected for ionosphere				896 274.242

Table 7. Final Results From Session III (All Values in Meters) (Continued)

III. MOBLAS Station Determinations (Set I)

	X	Y	Z	L (baseline length)
Quincy	-2 516 896.205	-4 198 843.129	+4 076 411.149	
Otay	-2 428 829.360	-4 799 748.846	+3 417 272.110	
Otay/Quincy	-88 066.845	+600 905.717	+659 139.039	896 274.357

IV. MOBLAS Station Determinations (Set II)

	X	Y	Z	L (Baseline Length)
Quincy	-2516895.824	-4198843.930	4076 410.467	
Otay	-2428829.029	-4799749.529	3417 271.371	
Otay/Quincy	-88066.795	+600905.599	659 139.097	896 274.315 ± .10

V. GEOCEIVER Mean Value: Otay/Quincy

	X	Y	Z	L (Baseline Length)
between GEOCEIVER reference marks	-88 142.040	+600 928.970	+659 117.720	896 281.661
transferred to MOBLAS reference marks	-88 065.229	+600 906.541	+659 139.809	896 275.317
empirically corrected by -.50 parts in 10^6 (NGS)	-88 065.185	+600 906.241	+659 139.479	896 274.869

VI. ARIES minus MOBLAS (Set I): Otay/Quincy

	X	Y	Z	L (Baseline Length)
	-.636	+.324	-.230	+.110
ARIES corrected for ionosphere				-.115

Table 7. Final Results From Session III (All Values in Meters) (Continued)

VII. MOBLAS (Set I) Minus Empirically Corrected GEOCEIVER: Otay/Quincy

	X	Y	Z	L (Baseline Length)
	-1.660	-.524	-.440	-.512

VIII. ARIES Minus MOBLAS (Set II): Otay/Quincy

	X	Y	Z	L (Baseline Length)
	-.686	+.442	-.288	+.152
ARIES corrected for ionosphere				-.073

IX. MOBLAS (Set II) Minus Empirically Corrected GEOCEIVER: Otay/Quincy

	X	Y	Z	L (Baseline Length)
	-1.610	-.642	-.382	-.553

X. ARIES Minus Empirically Corrected Geoceiver

	X	Y	Z	L (Baseline Length)
	-2.296	-.200	-.670	-.402
ARIES corrected for ionosphere				-.627

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