LUNAR LASER RANGING

EARTH ROTATION (UT0-UTC AND VARIATION OF LATITUDE) BY ANALYZING LUNAR LASER RANGING

FSG 94 M 01

J.Mueller, M.Schneider, U.Schreiber
Forschungseinrichtung Satellitengeodaesie (FSG), Technical University Munich
80290 Munich, Germany

M.Soffel, H.Ruder
Theoretical Astrophysics, University Tuebingen
Auf der Morgenstelle 10, 72076 Tuebingen, Germany

We have analyzed Lunar Laser Ranging (LLR) data acquired between 1970 and early 1994. The observations are taken from the usual five sites: McDonald (three locations), Grasse and Haleakala; some normal points and quick-look returns from Wettzell are added to test their quality. All in all more than 8500 LLR measurements are used.

In a first step outliers have been eliminated. Then we performed a least-squares fit to weighted observations and determined the parameters of the Earth-Moon system.

The ephemeris of the Moon and the planets are computed with our own ephemeris program; the lunar librations were integrated simultaneously. The initial values for the integration are taken from the ephemeris DE200. A detailed description of our analysis model is given e.g. in Mueller *et al.* (1991) or Mueller *et al.* (1992).

The constants adopted for the computations are those of the IAU recommendations resp. the IERS standards (1992); however some nutation coefficients had been changed by introducing better values (e.g. for the 9-year, the annual, the half-year and the half-month coefficients).

The station coordinates have been corrected for plate motion (NUVEL NNR-1 model); the base epoch for plate motion is December 10, 1991 (MJD 48600). For some stations clock biases have been estimated.

The Earth orientation parameters are taken from a solution generated by R. Gross called SPACE93; they are introduced as a priori values in our LLR model and will be improved in a second step.

The parameters determined are station coordinates (relativistic geocentric frame), reflector coordinates (relativistic selenocentric frame), position and velocity of the Earth-Moon barycenter for one epoch, position and velocity of the lunar barycenter for an initial epoch, physical libration angles and angular velocities for this epoch, the lowest mass multipole moments of the Moon, the mass of the Earth-Moon system, the lunar Love number and one dissipation parameter, the lag angle (lunar tidal acceleration), a correction to the luni-solar precession constant and the four (two in-phase and two out-of-phase) coefficients of the 18.6 year nutation period; for them constraints indicated in Williams *et al.* (1991) have been used. Besides these parameters rates for UT1 and polar motion have been estimated.

The post-fit residuals are analyzed by the daily-decomposition method (Dickey *et al.*, 1985) to obtain improved values for UT0-UTC and variation of latitude (VOL) for each reflector station pair on every night for which sufficient data are available (at least two normal points per night are needed); the time span between the first and the last normal point has to be 1.5 hours (in some cases a coverage of only 1 hour was accepted). 1507 pairs were found. In a further step the bad ones have been eliminated and the others have been smoothed using a spline filter. The series of Earth rotation parameters (UT0-UTC and VOL) have been provided to the IERS Central bureau, designated EOP(FSG) 94 M 01.

These improved values for the Earth rotation have been used in a further iteration of the global adjustment of the LLR data. The final results for the station coordinates have been provided to the IERS Central Bureau. Its designation is SSC(FSG) 94 M 01.

Besides the parameters sent to the IERS a lot of others have been determined and are available on request. To these parameters belong the main parameter of the Earth-Moon system mentioned above and relativistic quantities like the metric parameters gamma and beta, the Nordtvedt parameter eta (strong equivalence principle), the geodetic precession of the lunar orbit, the time variation of the gravitational constant, one parameter for testing Newton's inverse square law and one parameter indicating a violation of special relativity.

Acknowledgements. We wish to acknowledge and thank the staffs of Cerga, Haleakala, and McDonald Observatory for providing the normal points. We wish to thank R. Gross from JPL for providing his series of Earth rotation parameters. Support from the Deutsche Forschungsgemeinschaft is gratefully acknowledged.

References

Dickey, J.O., Newhall, XX, Williams, J.G., 1985: Earth Orientation from Lunar Laser Ranging and an Error Analysis of Polar Motion Services, *J. Geophys. Res*, **90**, No. B11, 9353-9362.

McCarthy, D.D. (ed.), 1992: IERS Standards (1992), *IERS Tech. Note 13*, Observatoire de Paris, Paris.

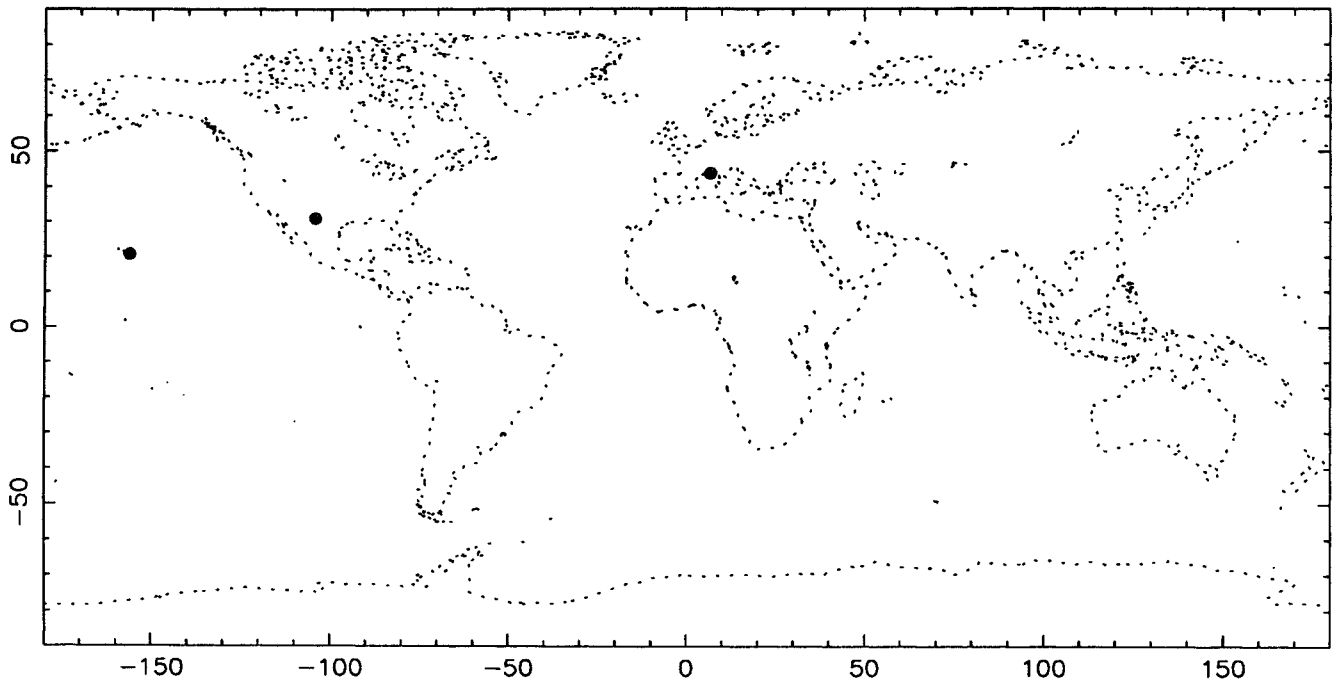
Mueller, J., Schneider, M., Soffel, M., Ruder, H., 1991: Testing Einstein's theory of gravity by analyzing Lunar Laser Ranging data, *Astrophys J.*, **382**, L101-L103.

Mueller, J., Schneider, M., Soffel, M., Ruder, H., 1992: New results for relativistic parameters from the analysis of LLR measurements, In: *Relativistic Gravity Research - With Emphasis on Experiments and Observations*, Eds.: J.Ehlers and G.Schaefer, Berlin: Lecture Notes in Physics 410, Springer, p. 87-99.

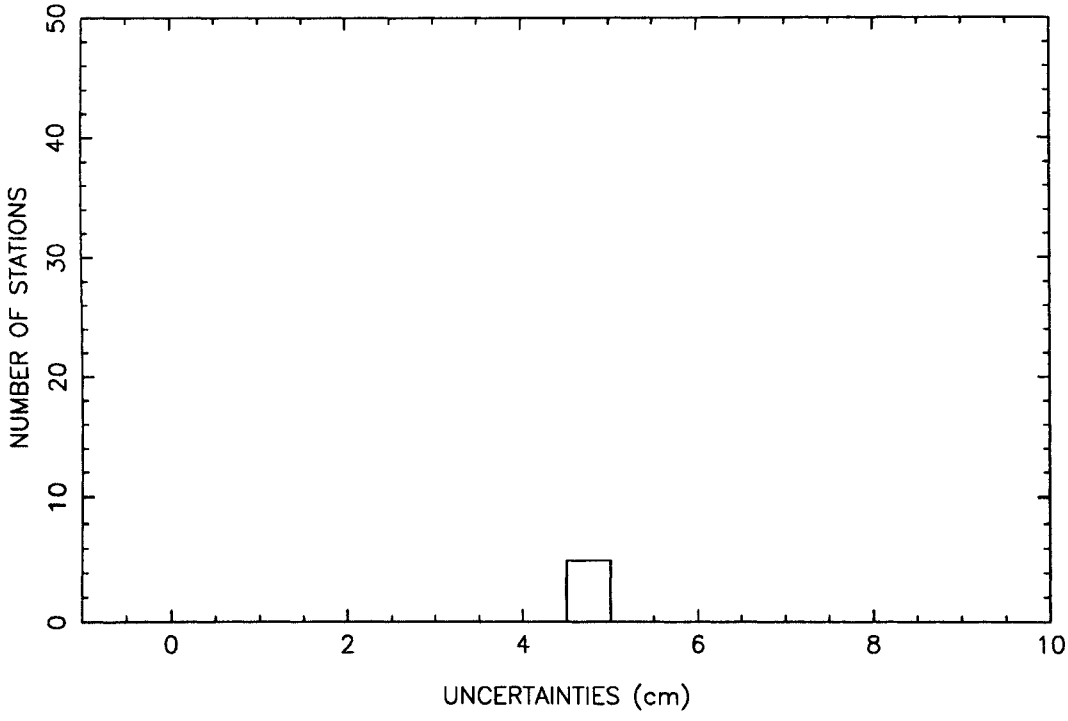
Williams, J.G., Newhall, XX, Dickey, J.O., 1991: Luni-Solar Precession: Determination from Lunar Laser Ranges, *Astron. Astrophys.*, **241**, L9-L12

Summary description of the terrestrial system attached to the set of station coordinates SSC(FSG) 94 M 01

1 - Technique :	LLR
2 - Analysis Center :	FSG/Techn. Univ. Munich
3 - Solution Identifier :	SSC(FSG) 94 M 01
4 - Software used :	FSG LLR software
5 - Relativity scale :	Geocentric
6 - Permanent tidal correction on station :	No
7 - Tectonic plate model :	NUVEL NNR-1
8 - Velocity of light (C) :	299792.458 km/sec
9 - Geogravitational constant (GMo) :	adjusted: 398600.448 km^3/sec^2 (geocentric)
10 - Reference epoch :	December 10, 1991 (MJD 48600)
11 - Adjusted Parameters :	cartesian coordinates of stations x, y, z (rates fixed)
12 - Definition of the origin :	Geocenter (center of mass)
13 - Definition of the orientation :	EOP from 1970 to 1994 taken from SPACE93 (aligned with IERS system)
14 - Constraint for time evolution :	Constrained to NUVEL NNR-1; estimation of UT1 and polar motion rates during the global solution



Distribution of the 3 sites of the terrestrial frame SSC(FSG) 94 M 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 5 stations of the terrestrial frame SSC(FSG) 93 M 01.

EOP(FSG) 94 M 01 From Oct 1970 to Jan 1994

Number of measurements per year and median uncertainties
Units : 0.001" for φ; 0.0001s for UT0.

YEAR	φ		UTO	
	Nb	Sigma	Nb	Sigma
1970	7	15.00	7	10.00
1971	21	15.00	21	10.00
1972	62	10.40	62	3.92
1973	105	15.00	105	10.00
1974	68	15.00	68	10.00
1975	82	15.00	82	10.00
1976	77	15.00	77	7.02
1977	70	15.00	70	10.00
1978	58	15.00	58	10.00
1979	62	15.00	62	10.00
1980	68	15.00	67	10.00
1981	29	15.00	29	10.00
1982	3	6.84	3	3.39
1983	6	15.00	6	10.00
1984	78	7.85	78	4.96
1985	175	7.80	175	3.61
1986	42	4.00	42	1.75
1987	39	3.68	39	1.26
1988	49	1.46	49	0.94
1989	51	1.34	51	0.79
1990	98	1.47	98	0.84
1991	63	1.58	63	0.85
1992	81	1.76	81	1.30
1993	102	1.61	102	0.82

EARTH ROTATION (UT0-UTC AND VARIATION OF LATITUDE) FROM LUNAR LASER RANGING

JPL 94 M 01

XX Newhall, J.G. Williams, J.O. Dickey
Jet Propulsion Laboratory, California Institute of Technology,
Pasadena, California 91109-8099, USA
(Contact: LOGOS::JGW or JGW@LOGOS.JPL.NASA.GOV)

Lunar Laser Ranging (LLR) data have been acquired and analyzed between April, 1970 and March, 1994. These data are used to estimate station locations, reflector locations, and lunar gravity and orbit parameters. Beginning in 1970, data acquisition was sufficiently dense to permit determinations of Earth rotation UT0 and variation of latitude (VOL). Values of UT0-UTC and VOL through 1992 have been submitted previously; 83 such values were derived from data acquired in 1993, and 20 values were obtained from early 1994 data.

The full range data set comprises 8582 normal points taken from five sites: the McDonald Observatory 2.7-meter telescope; the McDonald Laser Ranging Station (MLRS, situated in separate locations before and after a move in early 1988); the Haleakala Observatory on Maui, Hawaii; and the CERGA system in Grasse, France. These normal points are used to estimate the set of lunar and Earth-related parameters. The post-fit residuals are analyzed by the daily-decomposition method (Dickey *et al.*, 1985) to obtain estimates of UT0-UTC and variation of latitude for each station-reflector pair on every day for which sufficient data are available. This set of values is designated EOP(JPL) 94 M 01.

The IAU expression has been used for Greenwich mean sidereal time (Aoki *et al.*, 1982). The planetary and lunar ephemeris used in the fit was DE247/LE247. The lunar librations were integrated simultaneously with the ephemeris.

Plate motion has been applied to the station coordinates using the NNR-NUVEL 1 model of Argus and Gordon (1991). The base epoch for plate motion is January 1, 1991 (Julian day number 2448257.5).

The tidally driven diurnal and semidiurnal UT1 variations (M2, S2, N2, K1, O1, and P1), from the measured results in Herring (1993), have been added to the input UT1 file when fitting the ranges. Consequently, the output table of UT0 has these fast variations removed according to that model.

A correction to the IAU luni-solar precession constant (Lieske *et al.*, 1977; Lieske, 1979) has been taken as -3.3 mas/yr (Williams *et al.*, 1993). The correction has been made so as not to cause a rate change in UT (Williams and Melbourne, 1982; Zhu and Mueller, 1983). A theoretical obliquity-rate correction of -0.24 mas/yr (Williams, 1994) has been applied.

To the IAU nutations (Seidelmann, 1982) we have added the ZMOA corrections (Herring *et al.*, 1991a; 1991b) for the in-phase 9 yr, 1 yr, and half-month terms and for the in-phase and out-of-phase corrections for the half-year terms. Corrections to the 18.6 yr nutation coefficients were estimated, yielding

$$\Delta\varepsilon = 1.9 \cos\Omega + 0.9 \sin\Omega \text{ mas}$$
$$\sin\varepsilon\,\Delta\psi = -1.7 \sin\Omega + 0.7 \cos\Omega \text{ mas}$$

The constraint of the two in-phase terms (Williams *et al.*, 1991) includes a correction for the precession change and a connection between the changes of the two components. The two out-of-phase components are constrained to be in the ratio of 0.78. Subject to the constraint, the uncertainty in the nutation coefficients is about 1.2 mas, and the precession uncertainty is 0.4 mas/yr. Without the constraint these uncertainties would be larger.

With the production of the 1993 values of UT0-UTC and VOL a set of geocentric station locations has been established. The IERS designation is SSC(JPL) 94 M 01.

The separation between the Haleakala transmitter and receiver conforms to a survey. A range bias is estimated for Haleakala beginning in January, 1990. The separations between the McDonald sites were constrained to survey values.

The approximate uncertaintities in each of the spherical coordinates for all stations are: geocentric radius, 3 cm; longitude, 1 mas (3 cm); and latitude, 1.4 mas (4 cm). Each of the three spherical coordinates of the three estimated sites has significant correlation with the corresponding coordinate of the remaining two sites; these correlations are positive, implying that the coordinates shift together in the estimation process.

It should be noted that the McDonald 2.7 m telescope ceased LLR activity in June, 1985.

The station locations were derived using the formulation of the relativistic solar-system barycentric frame of reference. The transformation to the relativistic geocentric formulation requires the application of a scale factor.

Acknowledgments. We wish to acknowledge and thank the staffs of CERGA, Haleakala, the University of Texas McDonald Observatory, and the Lunar Laser Ranging associates. Normal points were constructed from individual photon returns by R. Ricklefs, P. Shelus, A. Whipple, and J. Ries at the University of Texas for the MLRS and for Haleakala data. D. O'Gara produced Haleakala normal points independently. C. Veillet provided normal points for the CERGA data. The planetary ephemeris was produced by E.M. Standish. This paper presents the results of one

phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

Aoki, S., Guinot, B., Kaplan, G.H., Kinoshita, H., McCarthy, D.D., and Seidelmann, P.K., 1982: The New Definition of Universal Time, *Astron. Astrophys.*, **105**, 1.

Argus, D.F., and Gordon, R.G., 1991: No-Net-Rotation Model of Current Plate Velocities Incorporating Plate Motion Model NUVEL-1, *Geophys. Res. Lett.*, **18**, 2039.

Dickey, J.O., Newhall, XX, and Williams, J. G., 1985: Earth Orientation from Lunar Laser Ranging and an Error Analysis of Polar Motion Services, *J. Geophys. Res.*, **90**, B11, 9353.

Herring, T. A., 1991a: The ZMOA-1990 Nutation Series, in *Proceedings of the 127th Colloquium of the International Astronomical Union, Reference Systems*, J. A. Hughes, C. A. Smith, and G. H. Kaplan, eds., U. S. Naval Obs., Washington, p. 157.

Herring, T. A., Buffet, B. A., Mathews, P. M., and Shapiro, I. I., 1991b: Forced Motions of the Earth: Influence of Inner Core Dynamics: 3. Very Long Baseline Interferometry Data Analysis, *J. Geophys. Res.*, **96**, 8259.

Herring, T. A., 1993: Diurnal and Semidiurnal Variations in Earth Rotation, in *Advances in Space Research*, vol. 13, No. 11, M. Feissel, ed., Pergammon, Great Britain, 147.

Lieske, J. H., Lederle, T., Fricke, W., and Morando, B., 1977: Expressions for the Precession Quantities Based upon the IAU (1976) System of Astronomical Constants, *Astron. Astrophys.*, **58**, 1.

Lieske, J. H., 1979: Precession Matrix Based on IAU (1976) System of Astronomical Constants, *Astron. Astrophys.*, **73**, 282.

Seidelmann, P. K., 1982: 1980 IAU Theory of Nutation: The Final Report of the IAU Working Group on Nutation, *Celest. Mech.*, **27**, 79.

Williams, J. G., 1994: Contributions to the Earth's Obliquity Rate, Precession, and Nutation, *Astron. J.* (in press).

Williams, J. G. and Melbourne, W. G., 1982: Comments on the Effects of Adopting New Precession and Equinox Corrections, in *Proceedings, High-Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations*, O. Calame, ed., D. Reidel, Hingham, MA, p. 293.

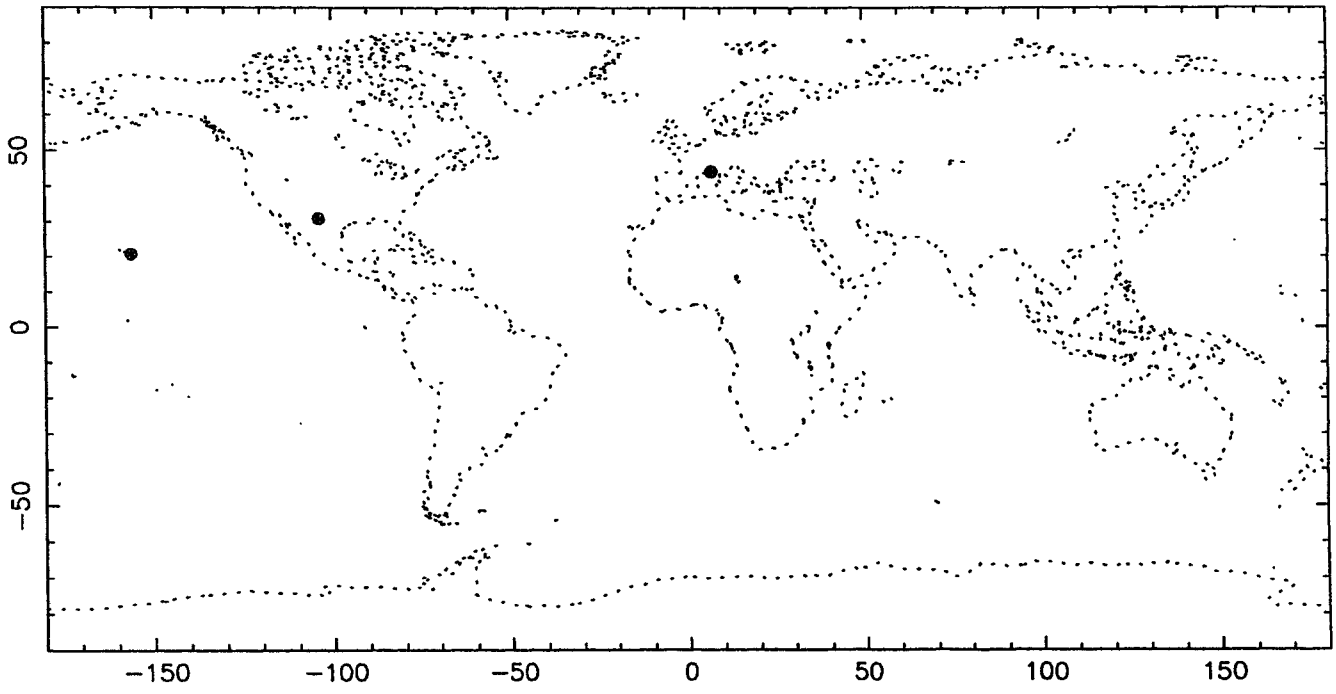
Williams, J.G., Newhall, XX, and Dickey, J.O., 1991: Luni-solar Precession: Determination from Lunar Laser Ranges, *Astron. Astrophys.*, **241**, L9.

Williams, J.G., Newhall, X X, and Dickey, J. O., 1993: Lunar Laser Ranging: Geophysical Results and Reference Frames, in *Contributions of Space Geodesy to Geodynamics: Earth Dynamics*, Geodynamics Series 24, D. E. Smith and D. L. Turcotte, eds., American Geophysical Union, Washington, D. C., 83.

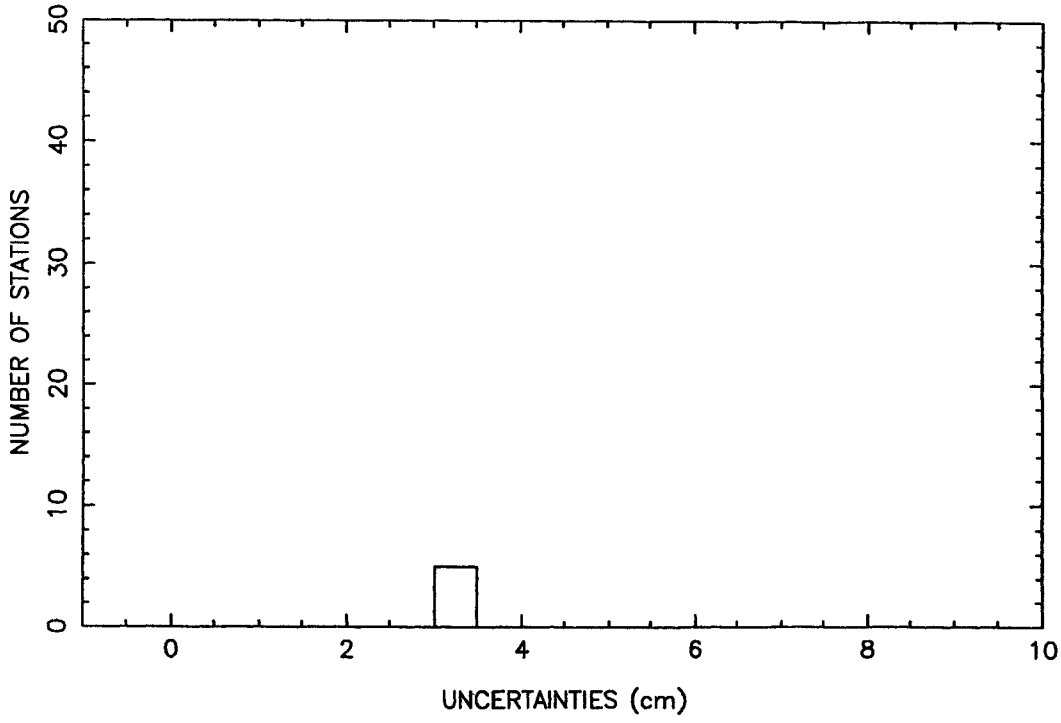
Zhu, S. Y., and Mueller, I.I., 1983: Effects of Adopting New Precession, Nutation, and Equinox Corrections on the Terrestrial Reference Frame, *Bull. Geod.*, **57**, 29.

Summary sheet for the description of the terrestrial system attached to the set of station coordinates SSC (JPL) 94 M 01

1 - Technique:	LLR
2 - Analysis center:	JPL
3 - Solution identifier:	SSC(JPL) 94 M 01
4 - Software used:	JPL LLR software
5 - Relativity scale:	SSB
6 - Permanent tidal correction on stations:	No separate correction.
7 - Tectonic plate model:	NNR-NUVEL 1
8 - Velocity of light (c):	299792458 m/sec
9 - Geogravitational constant (GMo):	From ephemeris solution $3986004428\ 10^{13}$ (SI). GM does not influence the LLR station radii.
10 - Reference epoch:	January 1, 1991 (JD 2448257.5)
11 - Adjusted parameters:	Spherical coordinates of stations (rates fixed) from full data span. Differences between three McDonald sites are constrained to surveys.
12 - Definition of the origin:	Geocenter (center of mass)
13 - Definition of the orientation:	Input Earth rotation values from 1970 to early 1994 taken from a file from R. Gross (a version of COMB-93 generated without LLR data) aligned with IERS system. Restricted by the uncertainties on the file, smoothed variation of latitude and UT0 corrections were made from LLR data during the global solution for stations, orbit, 18.6 yr nutations, etc. Daily corrections for UT0/VOL done after global fit.
14 - Constraint for time evolution:	It was necessary to solve for overall corrections to the UT1 and polar motion rates in the input UT1/polar motion file. Plate motion was not adjusted.



Distribution of the 3 sites of the terrestrial frame SSC(JPL) 94 M 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 5 stations of the terrestrial frame SSC(JPL) 94 M 01.

EOP(JPL) 94 M 01 From Apr 1970 to Mar 1994

Number of measurements per year and median uncertainties
Units : 0.001" for φ; 0.0001s for UT0.

YEAR	φ		UTO	
	Nb	Sigma	Nb	Sigma
1970	15	14.95	15	10.54
1971	34	13.49	34	7.92
1972	72	8.80	72	5.41
1973	102	14.99	102	8.06
1974	69	12.04	69	6.88
1975	87	11.07	87	7.37
1976	64	9.04	64	5.47
1977	68	7.03	68	4.29
1978	49	7.77	49	5.44
1979	65	6.29	65	4.46
1980	68	5.57	68	3.85
1981	45	7.75	45	4.03
1982	6	7.83	6	4.70
1983	0		0	
1984	26	5.06	26	2.66
1985	111	6.40	111	2.57
1986	28	4.77	28	1.76
1987	19	3.62	19	1.10
1988	71	2.06	71	1.05
1989	42	1.67	42	0.91
1990	89	1.60	89	0.99
1991	56	1.29	56	0.77
1992	53	0.95	53	0.68
1993	83	1.20	83	1.00
1994	20	0.76	20	0.42

DETERMINATION OF UNIVERSAL TIME BY LUNAR LASER RANGING

SHA 94 M 01

Jin Wenjing, Xu Huaguan, Huang Chengli, Shanghai Observatory, China

Lunar Laser Ranging (LLR) data have been analyzed during JD 2447187.0 - JD 2449345.0. These data set of McDonald (71111, 71112), Grasse (1910) and Haleakala (56610) contain 3030 normal points reflected from four reflectors.

Theoretical models and astronomical constants (solid earth tide and ocean tide etc) were adopted from IERS standards (1992). The influence of plate motion is taken into account with the NUVEL model. The base epoch for plate motion is January 1, 1988. The relativistic effects (propagation correction, scale factor and Lorentz effect) are considered. The planetary ephemeris DE310/LE310 and the lunar librations integrated simultaneously with the ephemeris were used for calculating the theoretical distances from the observing stations to the reflectors on the Moon. In this global solution more than 50 parameters like station and retro-reflector coordinates, lunar potential, and orbit parameters of the Earth-Moon system were estimated.

The post-fit residuals are analysed to obtain 365 values of UT0-UTC during this period. Due to the need of solving the normal equation, the span between the first and last normal points should be greater than 1.5 hour and more than two points per day are needed. The cylindrical station coordinates produced are designated SSC(SHA) 94 M 01.

The mathematical model is described in Jin *et al.* (1985). UT0 is calculated in one day interval. The precision of the normal point is taken as the weight of the observational equation.

Acknowledgments. We wish to thank Dr. Veillet and Dickey who supplied the planetary ephemeris DE310/LE310 and the global data of lunar laser ranging.

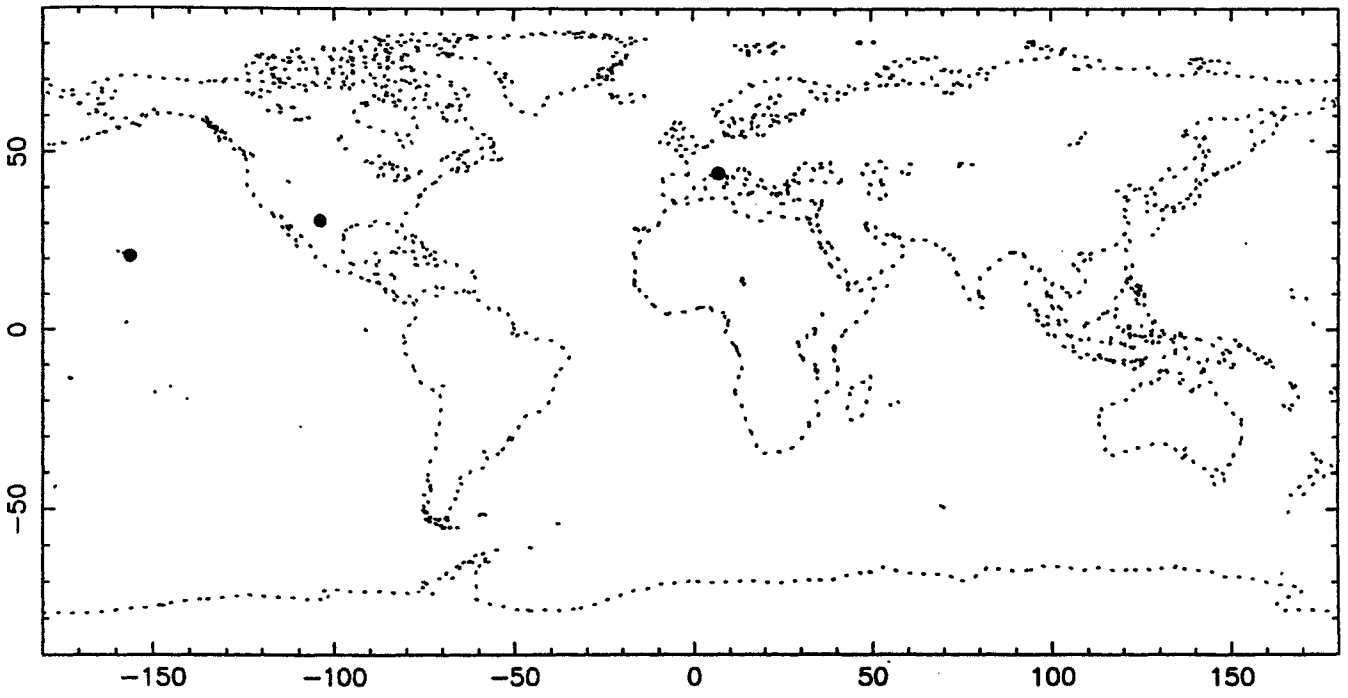
References

McCarthy, D.D. (ed.), 1992: IERS standards 1992, *IERS Technical Note 13*, Observatoire de Paris, Paris.

Jin Wenjing, Wang Qiangguo, 1985: Determination of ERP with lunar laser ranging and discussion of the influence of the adopted paremeters, *Proceedings of the international conference on earth rotation and the terrestrial reference frame*, p. 287-285.

Summary description of the terrestrial system attached to the set of station coordinates SSC(SHA) 94 M 01

1 - Technique:	LLR
2 - Analysis Center:	SHA
3 - Solution identifier:	SSC(SHA) 94 M 01
4 - Software used:	SHA LLR software
5 - Relativity scale:	SSB
6 - Permanent tidal correction on station:	No
7 - Tectonic plate model:	NUVEL
8 - Velocity of light:	299792458
9 - Geogravitational constant(GM):	$3.986004418\ 10^{14}$
10 - Reference epoch:	1988.0
11 - Adjusted parameters:	Cylindrical coordinates of stations (rates fixed)
12 - Definition of the origin:	Geocenter (center of mass)
13 - Definition of orientation:	EOP from 1988 to 1993 taken from IERS circular B
14 - Contraint for time evolution:	Contrained to NUVEL



Distribution of the 3 sites of the terrestrial frame SSC(SHA) 94 M 01.

EOP(SHA) 94 M 01 From Jan 1988 to Dec 1993

Number of measurements per year and median uncertainties
Units : 0.0001s for UT0

YEAR	UT0	
	Nb	Sigma
1988	54	1.45
1989	47	1.50
1990	81	1.40
1991	53	1.20
1992	45	0.90
1993	74	1.65

UT0 AND VARIATION OF LATITUDE DETERMINATION FROM LUNAR LASER RANGING OBSERVATIONS FOR 1969-1993

UTXMO 94 M 01

A. L. Whipple, J. Gyorgyey Ries, R. L. Ricklefs, P. J. Shelus, J. R. Wiant
McDonald Observatory / Department of Astronomy
The University of Texas at Austin, Austin, Texas 78712 (USA)

We have analyzed the total set of lunar laser ranging data available to us to determine UT0-UTC. These data were acquired between September, 1969 and March, 1994. A total of 8962 normal points, from the McDonald Observatory 2.7m telescope (which ceased operation in 1985), the McDonald Laser Ranging Station (saddle site and Mt. Fowlkes site) near Fort Davis, Texas, the Haleakala Observatory on Maui, Hawaii (which ceased operation in 1990) and the CERGA station in Grasse, France were used in this solution. The data were edited and weighted using an automated and objective scheme which identifies suspected outliers and adjusts station assigned weights to yield consistent distributions of the weighted residuals for all stations. There were sufficient data for 955 station/reflector pair estimations of UT0-UTC including 89 UT0 estimates, on 65 nights, in 1993. This is an increase of approximately 14% over last year.

Our method of analysis was similar to that described by Langley *et al.* (1981). We first used the MIT Planetary Ephemeris Program (PEP) to estimate corrections to the global parameters. The IERS standards were used with corrections made to the mass of the Earth-Moon system, the constant of precession, obliquity of the ecliptic, and the 18.6 year, annual, semi-annual, and fortnightly nutation terms. Adjustments to the MIT ITR-78 solution were made for the Earth-Moon barycenter orbit, lunar orbit, and lunar libration. The node of the Earth-Moon barycenter orbit was fixed to tie the longitude of the celestial reference frame. The AM0-2 plate motion model was used without adjustment. Our a priori Earth orientation series was the MIT UT1COM42/WOBCOM29 until 2 April 1988 (MJD 47253.0) followed by the University of Texas Center for Space Research (CSR) EOP(CSR) 93 L 02. We have biased the UT1COM42/WOBCOM29 series to the EOP(CSR) 93 L 02 series to reduce the arbitrary bias between our UT0 series and the IRIS VLBI 5-day and CSR SLR 3-day series. We estimated a piecewise linear spline for the polar motion components and UT1 to model long period deficiencies in the series. The orientation of the terrestrial reference frame was tied by fixing the zero point of the a priori ERP adjustments at 11 January 1985 (MJD 46076.0). The station coordinates, including a full correlation matrix, have been provided to the IERS Terrestrial Frame Section. We also estimated a third degree and order lunar potential, lunar love number, and lunar dissipation parameter along with the selenocentric retroreflector coordinates. Lastly, we estimated time delay biases, relative to MLRS, for the McDonald 2.7m, Maui and CERGA data.

IERS(1994) Technical Note No 17.

Following the global solution, we analyzed the post-fit residuals in the usual fashion (e.g., Stolz *et al.*, 1976) to determine nightly corrections to UT0 and variation of latitude. The nightly corrections were then added to the ERP corrections contained in the splines, and the a priori ERP series to obtain the final values of UT0-UTC and variation of latitude. A minimum of three normal points for each station/reflector pair and at least a 1.5 hour span of coverage were the criteria we adopted for the nightly UT0 estimations. The weighted root mean square of the final postfit range residuals, for the entire span of data, was 5.1 cm. The weighted rms of the postfit residuals for the 712 normal points obtained by the two active stations during 1993 was 2.9 cm.

We have compared our UT0 and variation of latitude series with the NEOS VLBI series. We calculated the bias, slope and weighted rms about the linear fit of the differences between our UT0R and variation of latitude estimates and those implied by the NEOS UT1 and polar motion values. Interpolation of the NEOS series was performed using a four point Newton interpolation scheme. Table 1 gives the results of this comparison for the period where all stations operated with short pulse lasers (1986.5 to 1994.2).

Table 1. Comparison between University of Texas McDonald Observatory LLR UT0R and variation of latitude (DPhi) and NEOS VLBI 5-day values. The period of comparison is 1986.5 to 1994.2. The epoch of the linear fit is 1990.5.

Station		Bias (mas)	Slope (mas/yr)	WRMS (mas)	N
CERGA	DUT0R:	1.22 +/- 0.11	-1.47 +/- 0.06	2.50	327
	DPHI:	-10.90 +/- 0.11	2.31 +/- 0.06	3.41	
MLRS	DUT0R:	5.07 +/- 0.50	-1.32 +/- 0.21	2.47	52
	DPHI:	5.45 +/- 0.54	-2.26 +/- 0.21	4.10	
Maui	DUT0R:	4.10 +/- 0.64	0.84 +/- 0.26	2.95	48
	DPHI:	11.68 +/- 0.84	0.73 +/- 0.35	3.85	

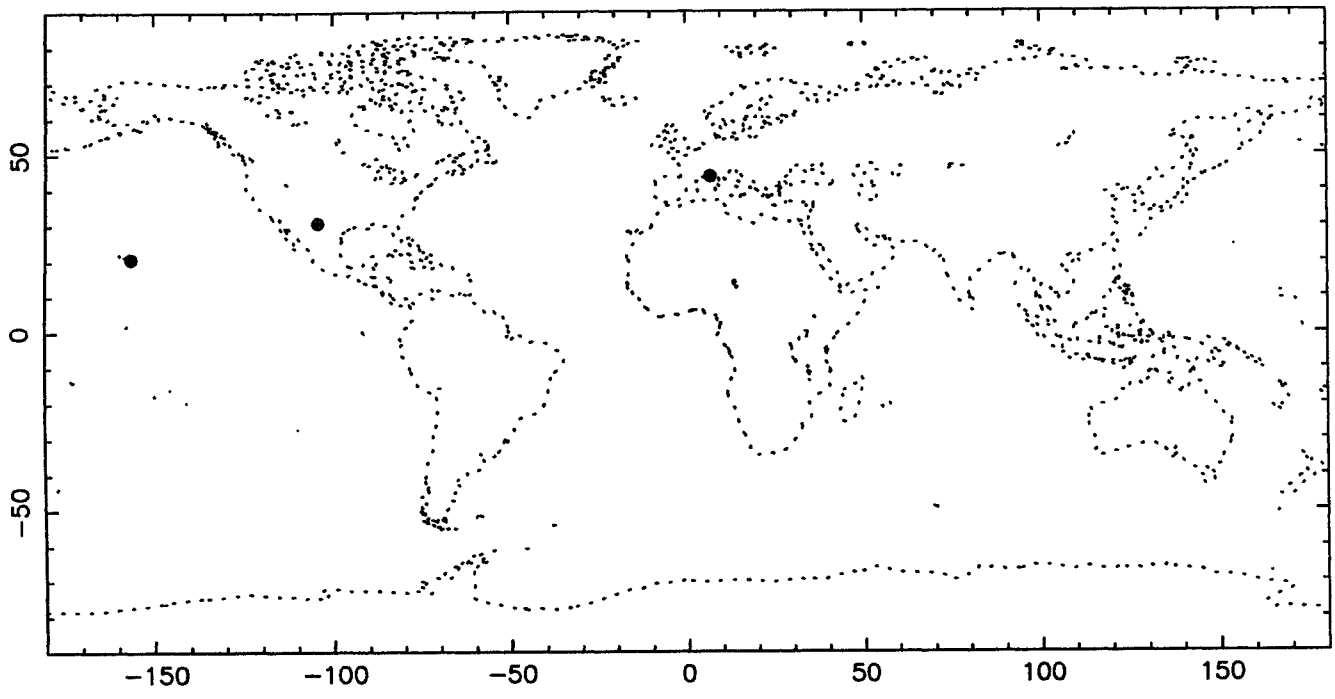
References

Langley, R.B., King, R.W., Shapiro, I. I., 1981: Earth Rotation from Lunar Laser Ranging, *J. Geophys. Res.*, **86**, 11913-11918.

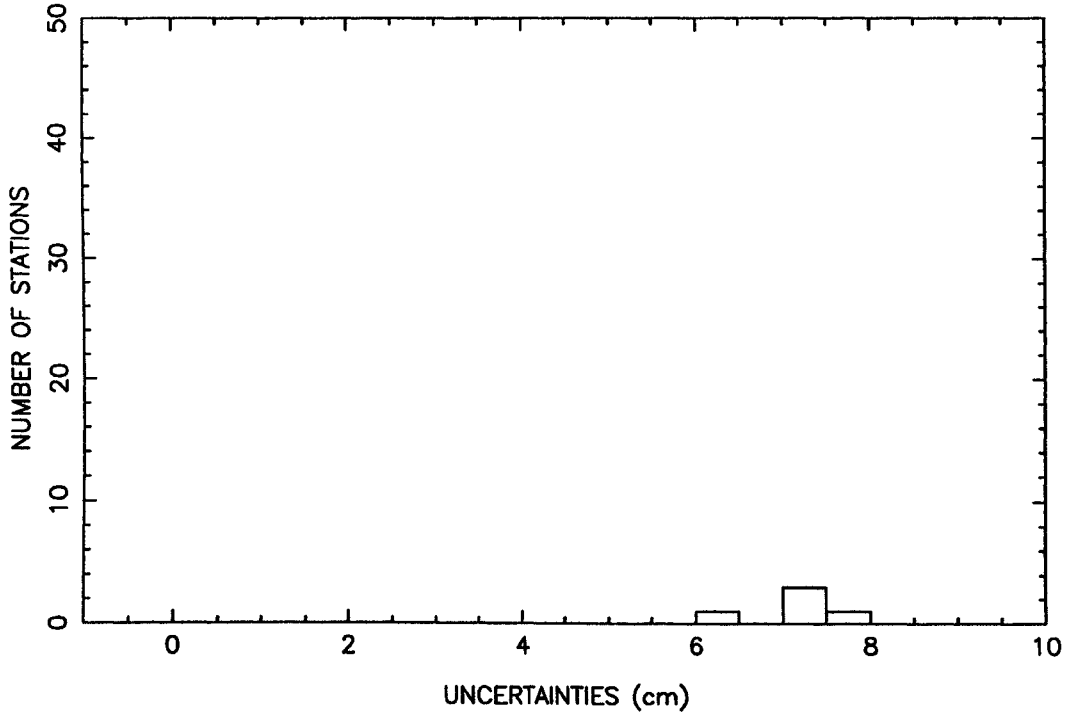
Stolz, A., Bender, P.L., Faller, J.E., Silverberg, E.C., Mulholland, J.D., Shelus, P.J., Williams, J.G., Carter, W.E., Gurnie, D.G., Kaula, W.M., 1976: Earth Rotation Measured by Lunar Laser Ranging, *Science*, **193**, 997-999.

Summary description of the terrestrial system attached to the set of station coordinates SSC(UTXMO) 94 M 01

1 - Technique:	LLR
2 - Analysis Center:	UT/McD
3 - Solution identifier:	UTXMO 94 M 01
4 - Software used:	PEP
5 - Relativity scale:	SSB
6 - Permanent tidal correction on station:	No
7 - Tectonic plate model:	AM0-2
8 - Velocity of light (C) =	299792458
9 - Geogravitational constant (GM) =	$3.98600443\ 10^{14}$ (geocentric)
10 - Reference epoch =	1984.0
11 - Adjusted parameters:	λ, φ, h
12 - Definition of the origin:	Geocenter
13 - Definition of the orientation:	Fixed to CSR EOP(CSR) 93 L 02 series at 11 Jan 1985
14 - Constraint for time evolution:	Constrained to AM0-2



Distribution of the 3 sites of the terrestrial frame SSC(UTXMO) 94 M 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 5 stations of the terrestrial frame SSC(UTXMO) 94 M 01.

EOP(UTXMO)94 M 01 From Oct 1970 to May 1994

Number of measurements per year and median uncertainties
Units : 0.001" for φ; 0.0001s for UT0

YEAR	φ		UT0	
	Nb	Sigma	Nb	Sigma
1970	5	46.90	5	6.61
1971	11	15.30	11	5.39
1972	48	8.50	48	5.61
1973	56	16.20	56	5.53
1974	28	7.60	28	4.59
1975	41	8.10	41	5.54
1976	41	7.60	41	5.20
1977	29	7.10	29	4.42
1978	22	8.30	22	4.70
1979	27	7.20	27	4.43
1980	33	6.50	33	3.90
1981	3	5.00	3	4.21
1982	0		0	
1983	6	5.60	6	3.57
1984	44	4.95	44	4.05
1985	106	8.20	106	4.00
1986	24	6.50	24	3.22
1987	24	9.05	24	3.10
1988	57	5.00	57	2.64
1989	46	4.10	46	2.91
1990	89	4.10	89	2.60
1991	58	3.65	58	2.31
1992	52	3.90	52	2.57
1993	88	4.00	88	3.39