SATELLITE LASER RANGING

EARTH ORIENTATION AND STATION COORDINATES FROM THE CENTRAL LABORATORY FOR GEODESY ANALYSIS: 1984-1994

CLG 95 L 01, 02

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Analysis of 586676 LAGEOS 1 normal points collected by the global SLR tracking network between January 1984 and June 1994 have been done. It was based on fitting the orbit in 30(31) day arcs. The monthly arcs were combined to form the basis for the multiyear global parameters determination. A set of 66 station positions at epoch 1984.0 and 46 station velocities were obtained. LODR series were calculated by forward differencing of the estimated UT1R values (fixing each month the first 5 day UT1-UTC values at IERS, Bulletin B values).

The SLRP-3 (Satellite Laser Ranging data Processor) version of the least-squares orbital analysis program was used for the data processing.

Models and constants

Reference Frame

CIS:	Mean equator and equinox of J2000.0
Planetary Ephemeris:	JPL DE200/LE200
Initial Earth Orientation:	IERS Bulletin B
Precession:	IAU(1976)
Nutation:	IAU(1980) + Herring 1987 corrections
Initial Station Coordinates:	ITRF91
Time evolution:	NNR-NUVEL1
Semi Major Axis of Earth:	6378136.3 m
Flattening 1/f:	298.257

Dynamic Model

Gravity Model:	NASA/GSFC GEM-T3, truncated at (20, 20), with GM0=3.986004360 10^{14} m^3/s^2 and A = 6378137 m as scale parameters with the geopotential coefficients and GM0 = 3.986004418 10^{14} m^3/s^2 with the two body term
C(2,1), S(2,1):	Applied according to IERS Standards
Third body:	Sun, Moon, Mercury, Venus, Mars, Jupiter and Saturn
Direct Solar Radiation Pressure:	Occultation by Earth and Moon and adjusted solar radiation coefficient
Air Drag:	Not applied
Albedo:	Not applied
Along Track Acceleration:	Adjusted
Solid Tides:	Wahr model (IERS Standards)
Ocean Tides:	Schwiderski model (IERS Standards)
Pole Tide:	IERS Standards

Relativistic Motion Equation Correction:	Applied according IERS Standards

Measurement Model

Tropospheric Refraction:	Marini-Murray model
Solid Earth Tide Displacement:	IERS Standards
Ocean Loading Site Displacement:	IERS Standards
Pole Tide:	IERS Standards
Relativistic Correction for Propagation:	Applied according IERS Standards

Data

LAGEOS 1 normal points generated from full rate data and received from GAOUA (1984-1988), GFZ (1989-1991) and CDDIS (1992-1994) were used. All data are equally weighted.

Constraints

The first 5 day values of UT1-UTC in each arc are fixed at IERS, Bulletin B values.

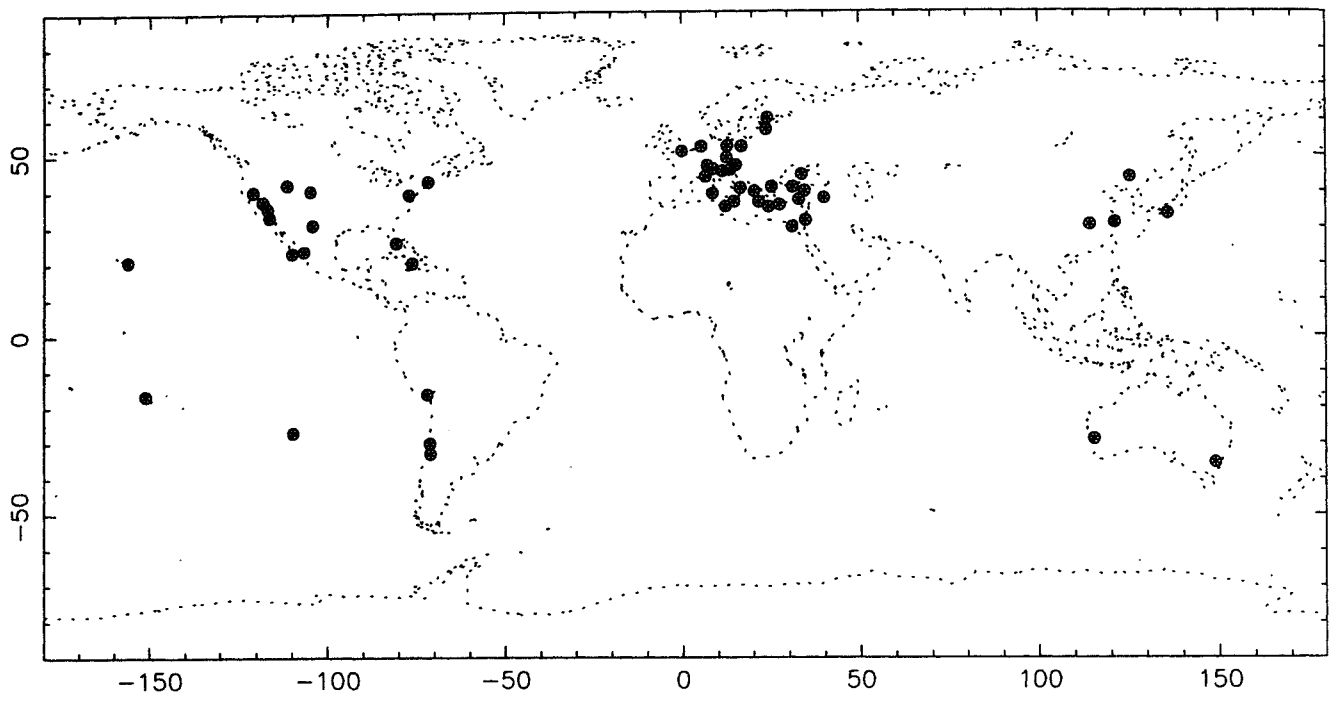
The latitude of Haleakala (7210) and the longitude and the latitude of Greenbelt (7105) are fixed at their ITRF91 values. The latitude and longitude rates of 20 sites are fixed at NNR-NUVEL1 velocities.

References

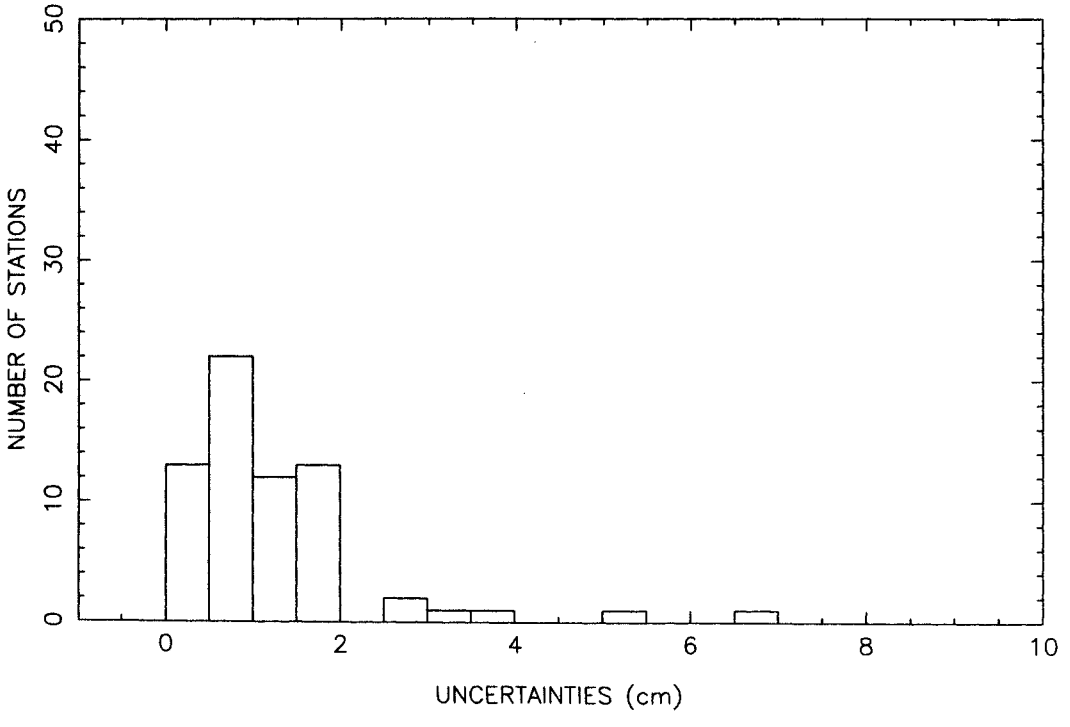
McCarthy, D.D. (ed.), 1992: IERS Standards (1992), *IERS Technical Note 13,* Observatoire de Paris, Paris.

Technical description of solution CLG 95 L 01

1 - Technique :	SLR
2 - Analysis Center:	CLG
3 - Software used:	SLRP-3
4 - Data span:	Jan 84 - Jun 94
5 - Celestial Reference Frame:	
a - Nature:	Dynamical, LAGEOS 1
b - Definition of the origin :	By fixing each month the first 5 day UT1-UTC at IERS Bulletin B values
6 - Terrestrial Reference Frame:	SSC(CLG) 95 L 01
a - Relativity scale:	Local Earth
b - Velocity of light:	299 792 458 m/s
c - Geogravitational Constant:	GM0 = 3.986004415 10^{14} m^3 /s^2 with the two body term GM0 = 3.986004360 10^{14} m^3/s^2 and A = 6378137 m as scale parameters with the geopotential coefficients
d - Permanent tidal correction:	No, only the periodic term have been applied
e - Definition of origin:	C(1,0)=0, C(1,1)=0, S(1,1)=0
f - Definition of orientation:	By fixing the latitude of Haleakala (7210) and the longitude and the latitude of Greenbelt (7105)
g - Reference Epoch	1984.0
h - Tectonic plate model:	NNR-NUVEL1
i - Constraint for time evolution:	By adopting the NNR-NUVEL1 values for 16 sites
7 - Earth orientation:	EOP(CLG) 95 L 01
a - A priori nutation model:	IAU(1980) + Herring 1987 corrections
b - Short-period tidal variations in x, y, UT1:	Not included
8 - Estimated parameters:	
a - Celestial frame:	
b - Terrestrial frame:	X0, Y0, Z0, XDOT, YDOT, ZDOT
c - Earth orientation:	X, Y, LODR
d - Others:	Orbital state vector Solar radiation coefficient Along track acceleration Love and Shida numbers Geogravitational parameter GM Selected set of 15 geopotential coefficients



Distribution of the 54 sites of the terrestrial frame SSC(CLG) 95 L 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 66 stations of the terrestrial frame SSC(CLG) 95 L 01.

EOP(CLG) 95 L 01 From Jan 1984 to Jun 1994

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for D

YEAR	X		Y		D	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1984	62	0.47	62	0.40	42	0.15
1985	37	0.33	37	0.32	25	0.11
1986	67	0.47	67	0.40	43	0.14
1987	73	0.39	73	0.37	51	0.14
1988	71	0.37	71	0.37	47	0.12
1989	73	0.44	73	0.43	50	0.16
1990	0		0		0	
1991	72	0.42	72	0.41	48	0.14
1992	49	0.47	49	0.41	33	0.14
1993	38	0.40	38	0.38	26	0.13
1994	38	0.48	38	0.49	26	0.15

EOP(CLG) 95 L 02 From Jan 1984 to Jun 1994

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for D

YEAR	X		Y		D	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1984	99	0.58	99	0.51	79	0.27
1985	59	0.39	59	0.40	47	0.21
1986	105	0.56	105	0.47	81	0.26
1987	90	0.47	90	0.45	70	0.25
1988	108	0.46	108	0.46	84	0.24
1989	108	0.55	108	0.49	85	0.31
1990	0		0		0	
1991	111	0.51	111	0.49	87	0.26
1992	74	0.55	74	0.48	58	0.27
1993	59	0.48	59	0.44	47	0.24
1994	56	0.58	56	0.58	44	0.29

EARTH ORIENTATION AND SITE COORDINATES FROM THE CENTER FOR SPACE RESEARCH SOLUTION

CSR 95 L 01

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Station positions and velocities were derived from a combination of Lageos-1 and Lageos-2 SLR data. Lageos-1 data from May 1976 through February 1995 and Lageos-2 data from October 1992 through February 1995 was used. Earth orientation parameters were computed only from the Lageos-1 data.

Mean positions for all sites were adjusted and both horizontal and vertical site velocities were adjusted for 47 sites with good observing histories. For all other sites, velocities were held fixed to those predicted by the NUVEL-1 NNR model. The solution for both positions and velocities was fiducial free, and the resulting reference frame was defined through the application of internal constraints on the rotation and rotation rate. The resulting system was then transformed to have no rotation or rotation rate with respect to ITRF93 following the method of Heflin *et al.* (1992). Note that the scale and geocenter were not included in this transformation to ITRF93, and remain as adjusted in the solution. This method of reference frame definition has replaced our previous method of fixing the latitude and longitude and their rates for the site at Haleakala (7210), and the latitude and latitude rate of the site at Goddard Spaceflight Center (7105).

The force and measurement models used for this solution conform generally to the IERS Standards, with the following exceptions:

1) The a priori gravity field was JGM-3, a state of the art gravity field derived as a joint effort by the Goddard Space Flight Center and the Center for Space Research.

2) The ocean tide model was an enhanced version of the Schwiderski model extrapolated to include 80 constituents complete through degree and order 20, assuming admittances which vary linearly with frequency. Some ocean tide coefficients were adjusted using Lageos-1 tracking data.

3) The solid tide model (dynamic effect) has been expanded to include third degree and fourth degree terms.

4) The geogravitational constant, GM, was 398600.4415 km^3/s^2.

5) The nominal plate motion model was NNR-NUVEL-1

6) The free core nutation period has been changed from 460 to 430 days.

7) Diurnal and semidiurnal variation in the EOP and in the motion of the geocenter for 15 tidal frequencies were simultaneously adjusted in the solution.

The data was weighted in a piecewise continuous, linearly interpolated model to reflect the improvement in laser hardware over the data span. The weights are larger than the true random component of the laser ranges in order to reflect unmodeled systematic errors, and are thus scaled so that the formal uncertainties on the Earth orientation parameters are consistent with their internal precision.

The solutions for orbit elements and Earth orientation parameters were computed using residuals from a long arc fit spanning the period from 7 May 1976 through 27 February 1995, a period of 18.8 years. The short arc adjustments were made at 3 day intervals subject to the constraint that the posteriori uncertainties were less than specified values, to allow for the change in data quantity over time. If the solution for a given 3 day interval yielded unacceptably large uncertainties on the adjusted parameters, the interval was extended by 3 days and the solution repeated. Thus, each final interval is a multiple of 3 days. For each interval, regardless of length, 6 Keplerian mean elements and Xp and Yp were adjusted. The UT1 estimates are obtained from the Lageos-1 node residuals, with the constraint that they follow the JPL SPACE94 series at periods longer than about 60 days [Gross, 1995].

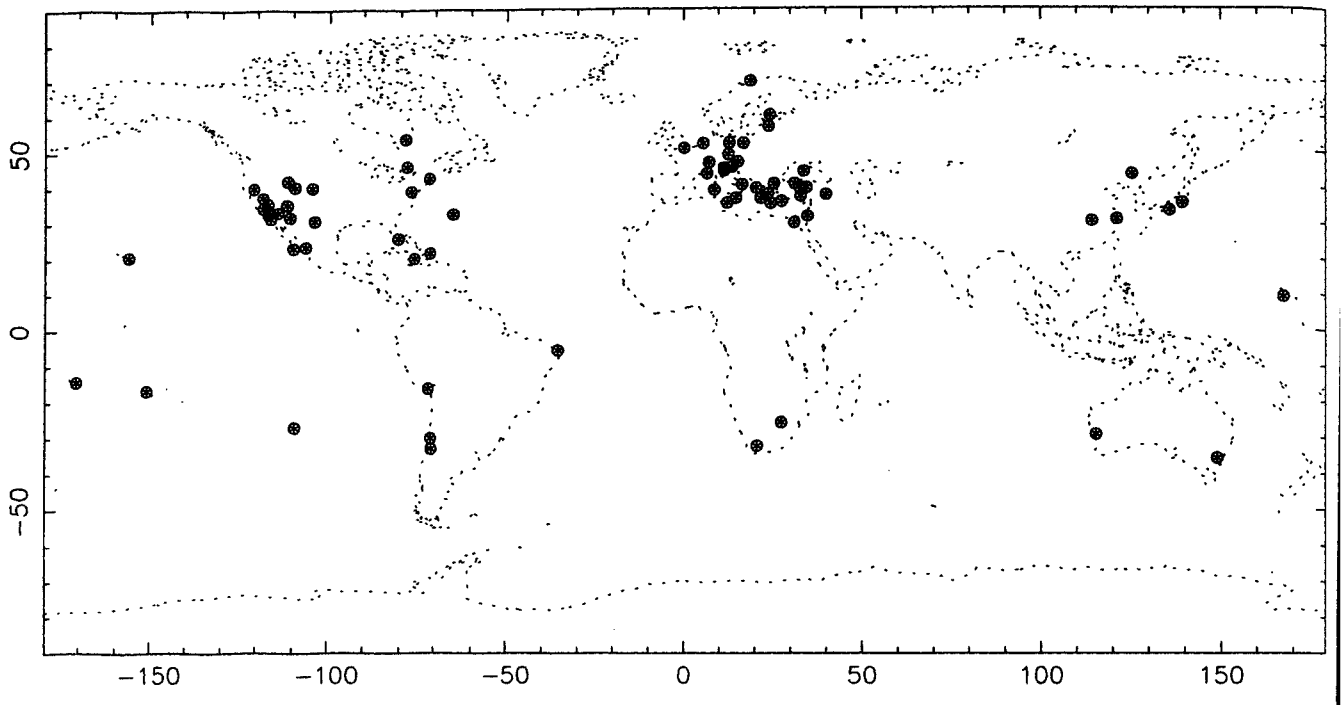
References

Gross, R.S., 1995: A Combination of EOP Measurements: SPACE94, *IERS Technical Note 19,* P. Charlot (ed.), Observatoire de Paris, Paris, p. C-1, C-4.

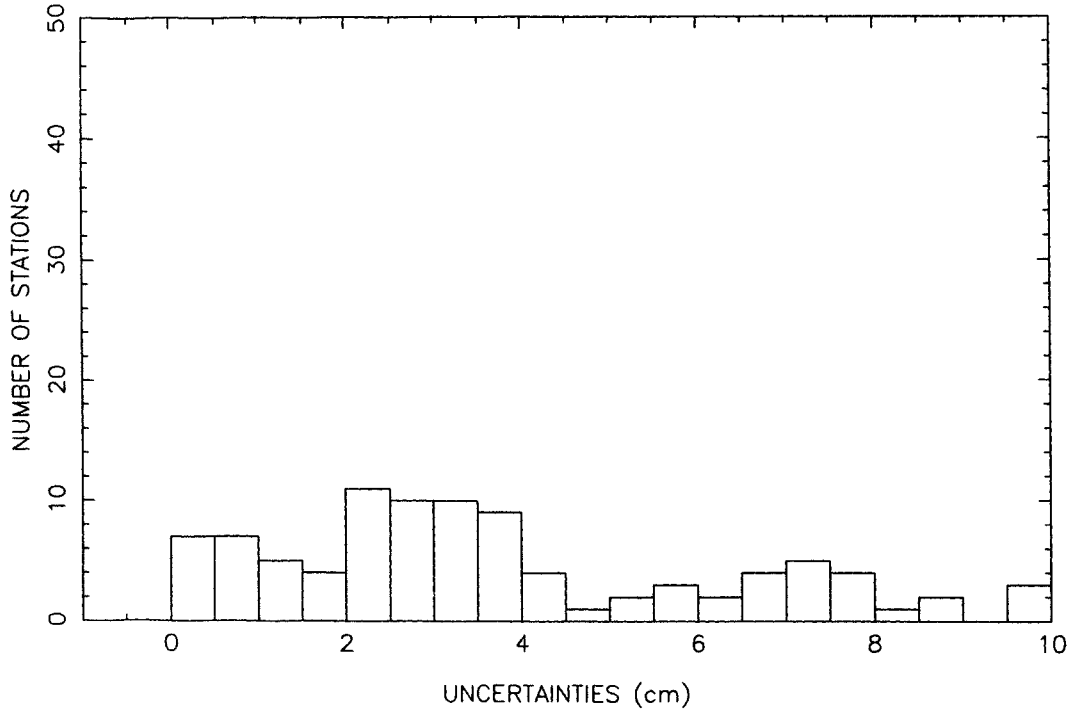
Heflin, M., Bertiger, W., Blewitt, G., Freedman, A., Hurst, K., Lichten, S., Lindqwister, U., Vigue, Y., Webb, F., Yunck, T., and Zumberge, J., 1992: Global Geodesy Using GPS Without Fiducial Sites, *Geophys. Res. Lett.,* **19,** No. 2, 131-134

Technical description of solution CSR 95 L 01

1 - Technique:	SLR
2 - Analysis Center:	CSR
3 - Software Used:	UTOPIA, GIPSY/OASIS-II routines used for reference frame definition
4 - Data span:	Station positions: Lageos-1 May 76-Feb 95, Lageos-2 Oct 92-Feb 95 Earth orientation :Lageos-1 May 76-Feb 95
5 - Celestial Reference Frame:	Not applicable
a - Nature:	dynamical, Lageos-1, Lageos-2
b - Definition of the orientation:	UT1 tie to SPACE94
6 - Terrestrial Reference Frame:	SSC(CSR) 95 L 01
a - Relativity Scale:	LE
b - Velocity of Light:	299 792 458 m/s
c - Geogravitational constant:	GM0 = 3.986004415 10^{14} m^3/s^2
d - Permanent tidal correction:	Yes
e - Definition of the origin:	C10=C11=S11=0
f - Definition of the orientation:	No net rotation with respect to ITRF93
g - Reference Epoch:	1993.0
h - Tectonic plate model:	NNR-NUVEL1
i - Constraint for time evolution:	No net rotation rate with respect to ITRF93
7 - Earth Orientation:	EOP(CSR) 95 L 01
a - A priori nutation model:	IAU(1980) + 5 frequency correction formula
b - Short period tidal variations in x,y,UT1:	diurnal and semidiurnal variations at 8 frequencies adjusted simultaneously. Values reported do not include these variations.
8 - Estimated parameters:	
a - Celestial frame:	Orbital elements every 3 days
b - Terrestrial frame:	free network X0,Y0,Z0,Xdot,Ydot,Zdot for 47 sites adjusted to fit ITRF93.
c - Earth orientation:	x, y and UT1R-TAI every 3 days, diurnal and semidiurnal tidal terms in x, y, UT1, Xg, Yg, Zg (geocenter)
d - Others:	station range biases for every site every 15 days



Distribution of the 74 sites of the terrestrial frame SSC(CSR) 95 L 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 117 stations of the terrestrial frame SSC(CSR) 95 L 01. 23 stations with uncertainties larger than 10 cm are not shown.

EOP(CSR) 95 L 01 From May 1976 to Jul 1995

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y ; 0.0001s for UT1

YEAR	X		Y		UT1	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1976	33	12.65	33	14.34	33	7.14
1977	71	12.81	71	11.99	71	6.76
1978	72	11.90	72	10.22	72	6.51
1979	76	9.34	76	9.66	76	5.94
1980	117	5.40	117	3.46	117	3.01
1981	112	5.19	112	3.16	112	2.59
1982	113	3.47	113	2.73	113	2.25
1983	118	2.80	118	2.64	118	1.70
1984	121	1.24	121	1.09	121	0.94
1985	121	1.09	121	0.90	121	0.76
1986	122	0.89	122	0.82	122	0.70
1987	122	0.60	122	0.55	122	0.46
1988	122	0.47	122	0.51	122	0.39
1989	121	0.48	121	0.46	121	0.40
1990	122	0.45	122	0.47	122	0.37
1991	122	0.51	122	0.50	122	0.39
1992	122	0.48	122	0.48	122	0.39
1993	122	0.45	122	0.39	122	0.33
1994	121	0.47	121	0.44	121	0.32
1995	71	0.37	71	0.36	71	0.29

EARTH ROTATION AND STATION COORDINATES COMPUTED FROM SLR AND GPS OBSERVATIONS

EOP(DUT) 95 L 02
SSC(DUT) 95 C 02

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The solution EOP(DUT) 95 L 02 consists of a coherent set of Earth Orientation Parameters (EOPs), determined from SLR observations of LAGEOS-1 taken in the period September 1983 to December 1993 and of LAGEOS-2 taken in the interval October 1992 until December 1993. The EOPs have been determined for 3-day intervals. An essential element of this computation is the development of a model for instantaneous station positions, SSC(DUT) 95 C 02, which is a combined solution based on the SLR observations already mentioned and GPS measurements taken in the period May 1989 (EUREF-89), August 1992 and 1994 (WEGENER/GPS92 and WEGENER/GPS94) and January 1993 - December 1994 (European IGS stations).

The computation of EOPs was performed in a 2-step approach: first, the model for station positions and motions was derived, and next, the polar motions parameters were computed w.r.t. this stable reference.

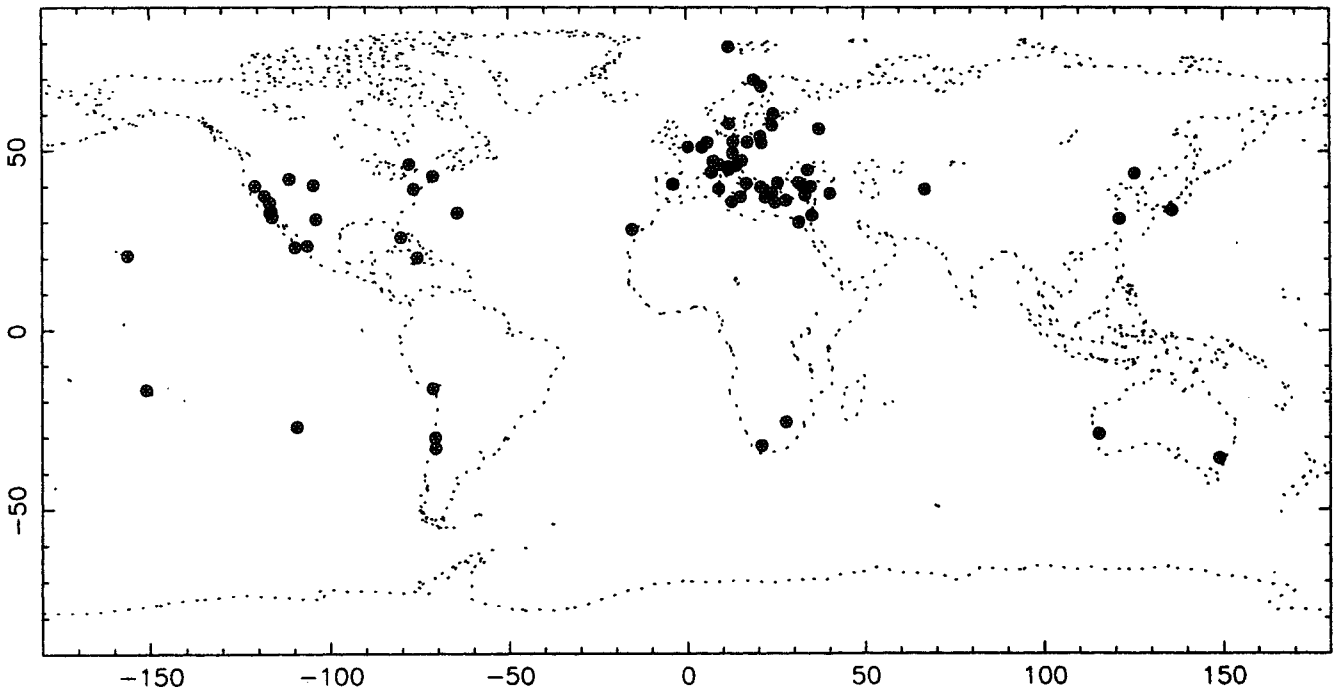
The model for the station positions and velocities was based on a series of independent network solutions, determined either from SLR or from GPS, and covering the periods mentioned above. In the computation of these individual network solutions, tectonic deformations were not modeled or estimated. This is reasonable since the subintervals in which the data were analyzed typically cover a period of 3 months. For the orbit computations, each SLR data-interval was sub-divided into consecutive 7-day data arcs, and each GPS interval (the full 2-week period for the EUREF89, WEGENER/GPS92 and WEGENER/GPS94 campaigns, and 1 month for the IGS solutions) into successive 1-day data arcs. Here, all tracking information was combined for the computation of station coordinates. The computation models are in very close agreement with the IERS Standards, with a few exceptions: in the SLR analysis, (i) the JGM-1 solution was used for the modeling of the gravity field and the ocean tide, (ii) ocean loading and atmospheric pressure loading were not taken into account, (iii) no plate motion model was applied, and (iv) new values for GM, ae and the flattening of the Earth were used. As for the GPS analysis, ocean loading and at pressure loading were not applied.

Next, the series of network solutions were converted into a coherent model for station positions as a linear function of time. In the computations, Helmert parameters for scale (GPS and LAGEOS-2), orientation and origin were estimated for all individual network solutions but one. In addition, the motion of 12 global stations was constrained to the NUVEL-1a NNR value by applying an a priori standard deviation of 1 mm/yr. The remainder of the parameters were adjusted freely, except for the motions of a few stations with a very weak tracking history, which were consequently kept fixed at the NUVEL values.

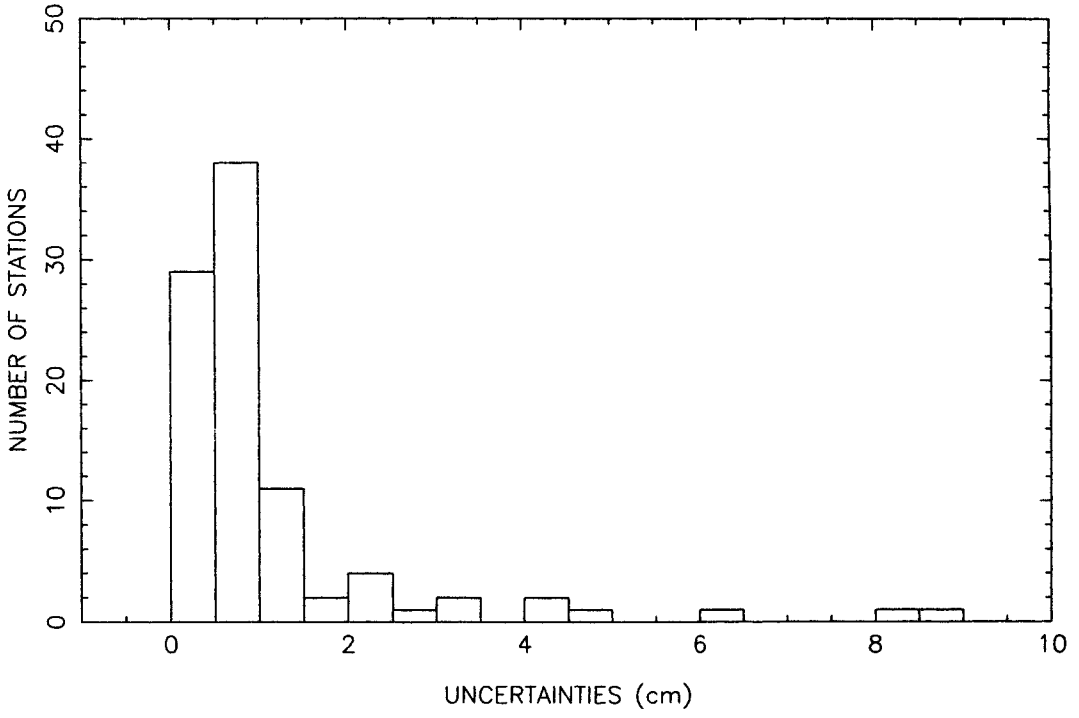
In the second step, the resulting model for instantaneous station positions was back-substituted into the previous step: the computations were repeated, but now with these station positions held fixed and the pole position and UT1 parameters estimated freely. Since the GPS networks analysed here are very regional, this second step was executed for the SLR component only. The computation model and scheme used was identical to that of the first step.

Technical description of solution DUT 95 C 02

1 - Technique :	combined SLR and GPS
2 - Analysis center:	DUT
3 - Software used:	GEODYN-2, SOLVE, GIPSY
4 - Data span:	September 1983 - December 1993
5 - Celestial Reference Frame:	n.a.
a - Nature:	dynamical
b - Definition of the orientation:	fixing EOP at IERS EOP 90 C 04
6 - Terrestrial Reference Frame:	SSC(DUT) 95 C 02
a - Relativity scale:	LE
b - Velocity of light :	299792458 m/s
c - Geogravitational constant:	398600.4415 10^9 m^3/s^2
d - Permanent tidal correction:	yes
e - Definition of origin:	C(1,0) = C(1,1) = S(1,1) = 0
f - Definition of orientation:	Bayesian constraint on 12 global positions (stations), a priori EOPs at IERS EOP 90 C 04
g - Reference epoch:	January 1, 1988
h - Tectonic plate model:	NNR-NUVEL1A a priori for 12 sites (Yarragadee, Easter Island, Greenbelt, Platteville, Huahine, Mazatlan, Maui, Wettzell, Graz, RGO, Orroral Valley, Kootwijk); Bayesian constraint of 0.001 m/yr. Remainder of stations: free solutions (except for weak stations with no information content)
i - Constraint for time evolution:	approximately NNR-NUVEL1A (for 12 stations); a priori EOPs at IERS EOP 90 C 04
7 - Earth orientation:	EOP(DUT) 95 C 02
a - Nutation model:	IAU(1980)
b - Short-period tidal variations in x, y, UT1:	x, y: no. UT: yes, with approximation of UT1-UTR as in IERS software. Report includes UT1.
8 - Adjusted parameters:	
a - Celestial Frame:	n.a.
b - Terrestrial Frame:	X0, Y0, Z0 (for selected 12 stations); X0, Y0, Z0, Xdot, Ydot, Zdot (remainder)
c - Earth Orientation:	x , y , UT1 at 3-day intervals
d - Others:	n.a.



Distribution of the 75 sites of the terrestrial frame SSC(DUT) 95 C 02.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 94 stations of the terrestrial frame SSC(DUT) 95 C 02. 1 station with uncertainty larger than 10 cm is not shown.

EOP(DUT) 95 L 02 From Sep 1983 to Jan 1994

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for UT1

YEAR	X		Y		UT1	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1983	40	0.45	40	0.46	40	0.33
1984	120	0.35	120	0.30	120	0.28
1985	48	0.49	48	0.33	48	0.33
1986	117	0.29	117	0.25	117	0.23
1987	119	0.27	119	0.23	119	0.21
1988	121	0.27	121	0.26	121	0.22
1989	119	0.24	119	0.22	119	0.20
1990	121	0.22	121	0.21	121	0.17
1991	120	0.25	120	0.24	120	0.20
1992	120	0.22	120	0.21	120	0.18
1993	121	0.17	121	0.15	121	0.14
1994	1	0.26	1	0.24	1	0.24

EARTH ROTATION AND TERRESTRIAL REFERENCE FRAME FROM LAGEOS I AND LAGEOS II DATA ANALYSIS

GAOUA 95 L 02

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Solution GAOUA 95 L 02 is a set of 91 station coordinates and 50 site velocities as well as a corresponding set of Earth rotation parameters.

Input data consists of satellite normal points (mostly release B) collected during 51885 passes of Lageos I since Sep. 1983 and 8278 passes of Lageos II since October 1992. The software package Kiev-Geodynamics-5.1 has been used for data processing.

The models and constants used for the analysis follows the IERS recommendations with the following exceptions:

- Earth gravity field is modelled according to GSFC/CSR UT JGM-3 model truncated at 20x20;
- Ocean tide model is JGM-2;
- Expanded solid tide model includes 32 tidal waves and 3d degree terms in force model;
- Earth backscattered and termal radiation is included in force model;
- short period tidal variations of EOP are modelled according to Herring (1993).

For the analysis the whole interval of data was divided into 15-day arcs. In the first step, only the orbits of LAGEOS I & II were adjusted over each arc. In the second step, the combination of the 15-day arcs yielded the final solution, consisting of parameters listed in the technical description below. By contrast with the previous year solution, orbital elements (except the longitude of ascending node) were adjusted every 15 days in this step. Along-track acceleration and satellite reflectance coefficients have been fixed. Postfit RMS of range modeling are usually within 3.5 - 8 cm.

Earth rotation parameters (x, y and UT1) were adjusted at 3 day intervals. In the case of poor data distribution or lack of observing stations, ERP were held fixed to EOP(IERS) 90 C 04.

The terrestrial reference system is attached to ITRF91 by fixing the latitude of station 7210 and the longitude and latitude of station 7105. Time evolution of the system is modelled by NNR-NUVEL1 for sites with either small amount of data or short-term activity periods. The velocities of 50 sites (61 collocated stations) having long observing history and sufficient amount of high quality data have been estimated and linked to NNR-NUVEL1 by fixing the latitude change rate of station 7210 and the longitude and latitude change rates of station 7105. The reference epoch for the site positions is 1993.0 (MJD 48988).

Acknowledgments

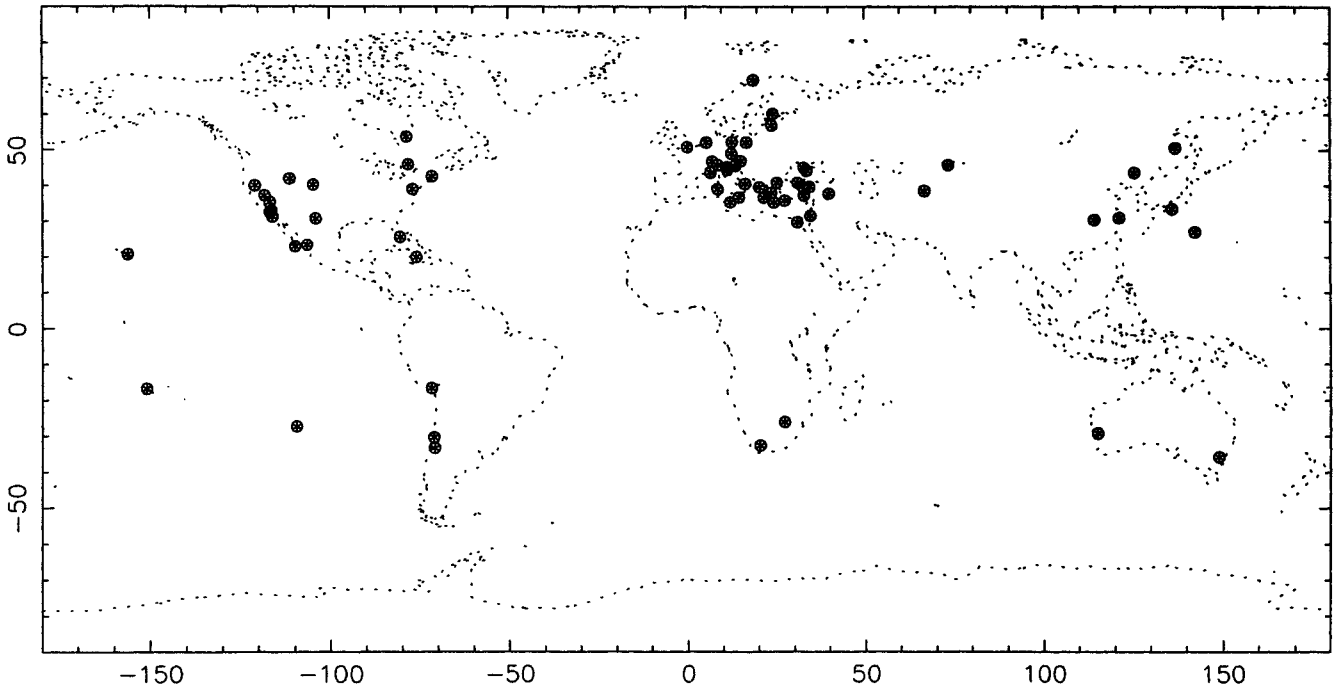
This work has been done partly thanks to the International Science Foundation Grant No US4000.

References

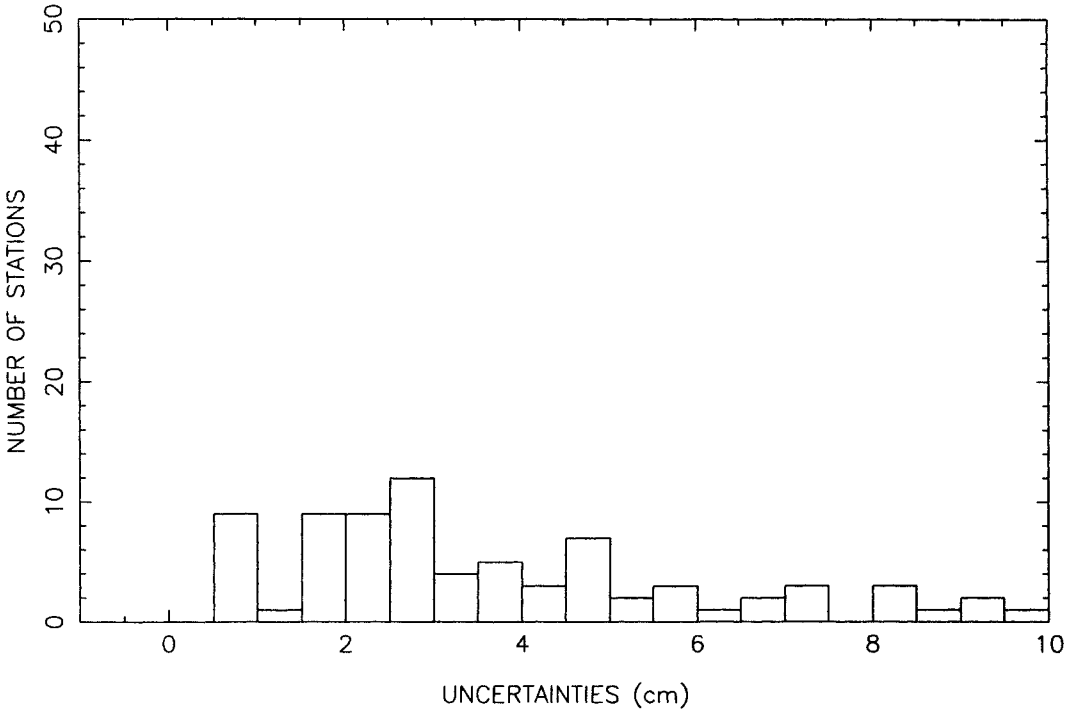
Herring, T.A., 1993: Diurnal and Semidiurnal Variations in Earth Rotation, *Proceedings of the COSPAR World Space Congress, Adv. Space Res.*, **13**, 11281-11290.

Technical description of solution GAOUA 95 L 02

1 - Technique:	SLR to LAGEOS I & II
2 - Analysis Center:	GAOUA
3 - Software used:	KIEV-GEODYNAMICS - 5.1
4 - Data span:	Sep 1983 - Oct 1994 (MJD 45581 - 49656)
5 - Celestial Reference Frame:	
a - Nature:	dynamical
b - Definition of the orientation:	
6 - Terrestrial Reference Frame:	SSC(GAOUA) 95 L 02
a - Relativity scale:	LE
b - Velocity of light:	299792458 m/s
c - Geogravitational constant:	$3.986004415\ 10^{14}\ m^3/s^2$
d - Permanent tidal correction:	Yes
e - Definition of origin:	C10=C11=S11=0
f - Definition of orientation:	EOP values from EOP(IERS) 90 C 04, latitudes of 7105 (Greenbelt) and 7210 (Haleakala) and longitude of 7105 fixed to ITRF91
g - Reference epoch:	1993.0 (MJD 48988)
h - Tectonic plate model:	NNR-NUVEL1
i - Constraint for time evolution:	Fixed rates of change of two latitudes (7105 and 7210) and one longitude (7105)
7 - Earth orientation:	EOP(GAOUA) 95 L 02
a - A priori nutation model:	IAU1980 + corrections EOP(IERS) 90 C 04
b - Short-period tidal variations in x, y, UT1:	added to EOP(IERS) 90 C 04 according to Herring (1993). EOP(GAOUA) 95 L 02 does not contain short-period tidal variations
8 - Estimated Parameters:	
a - Celestial Frame:	
b - Terrestrial Frame:	X0, Y0, Z0, Xdot, Ydot, Zdot; h0 and hdot for 7105; h0, lambda0, hdot, lambdadot for 7210
c - Earth Orientation:	Xp, Yp, UT1-UTC at 3-day intervals
d - Others:	5 keplerian elements (longitude of ascending node was fixed) at 15-day intervals for Lageos I & II



Distribution of the 69 sites of the terrestrial frame SSC(GAOUA) 95 L 02.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 91 stations of the terrestrial frame SSC(GAOUA) 95 L 02. 14 stations with uncertainties larger than 10 cm are not shown.

EOP(GAOUA) 95 L 02 From Sep 1983 to Oct 1994

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for UT1

YEAR	X		Y		UT1	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1983	39	0.43	39	0.42	39	0.34
1984	122	0.38	122	0.31	122	0.27
1985	122	0.34	122	0.26	122	0.25
1986	122	0.32	122	0.27	122	0.23
1987	121	0.27	121	0.23	121	0.21
1988	122	0.25	122	0.24	122	0.20
1989	122	0.26	122	0.24	122	0.21
1990	122	0.23	122	0.22	122	0.19
1991	121	0.28	121	0.26	121	0.22
1992	122	0.28	122	0.25	122	0.20
1993	122	0.19	122	0.16	122	0.14
1994	98	0.22	98	0.19	98	0.16

SOLUTION FOR THE TERRESTRIAL REFERENCE FRAME BASED ON LAGEOS LASER RANGING DATA

GFZ 95 L 01, L 02

H. Montag, Ch. Reigber, W. Sommerfeld, G. Dick
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1. Station Coordinates

Using Satellite Laser Ranging (SLR) data of Lageos 1 and Lageos 2 the new Set of Station Coordinates SSC(GFZ) 95 L 01 was determined. The constants and model parameters implemented in the software package EPOS.PV1 are conform to the IERS Standards (McCarthy, 1992) with the exception, that the tidal variations in UT1 caused by zonal tides with periods bigger than 35 days are not considered, the nutation corrections derived by VLBI were included, and instead of GEM-T1 the gravity model JGM-3 was applied. The gravity model also differs from the last year solution. Therefore a new homogeneous set of station coordinates using the data from 1986, January (MJD: 46443) until September, 1994 (MJD: 45599) was derived. Generally, the SLR data were weighted according to their estimated accuracy. In addition, several non-permanent stations were included with smaller weights in order to reduce the influence of a changing station distribution. The solution SSC(GFZ) 95 L 01 contains 77 marker positions at 69 stations. For 45 stations the data distribution allowed to adjust the site motions simultaneously (co-located markers at one station were constrained with a weight of 105 to have the same velocity). For the other stations the velocities were held fixed to those of the NUVEL-1 no net rotation model (de Mets *et al.*, 1990). The Technical Description contains more details on the adopted model for the terrestrial system. The reference epoch is 1988.0. The origin of the reference system was defined by C10 = C11 = S11 = 0. The orientation was constrained by fixing the latitude and longitude for station 7840 and the latitude for 7105. Additionally, no common net rotation was permitted relative to the ITRF92. Corrections due to the permanent tidal deformation of the Earth were applied. The time evolution of the station coordinates is constrained by adopting velocities from the NUVEL1 model for the above mentioned components of the two stations.

2. Earth Orientation Parameters

Based on the described SSC(GFZ) 95 L 01 two sets of Earth Orientation Parameters (pole coordinates and length of day - LOD) with different time resolutions were determined. The main solution EOP(GFZ) 95 L 01 has a time resolution of 5 days; the time resolution of EOP(GFZ) 95 L 02 is three days. Both series beginning in 1980 were continued till September 1994. The estimated standard deviations are about 0.1 mas for the pole coordinates and 0.006 ms for LOD. The accuracy is mostly influenced by the data distribution; therefore it could be improved by including LAGEOS 2 data since its launch in October, 1992. The accuracies are estimated to be about 0.3 mas and 0.05 ms, respectively.

References

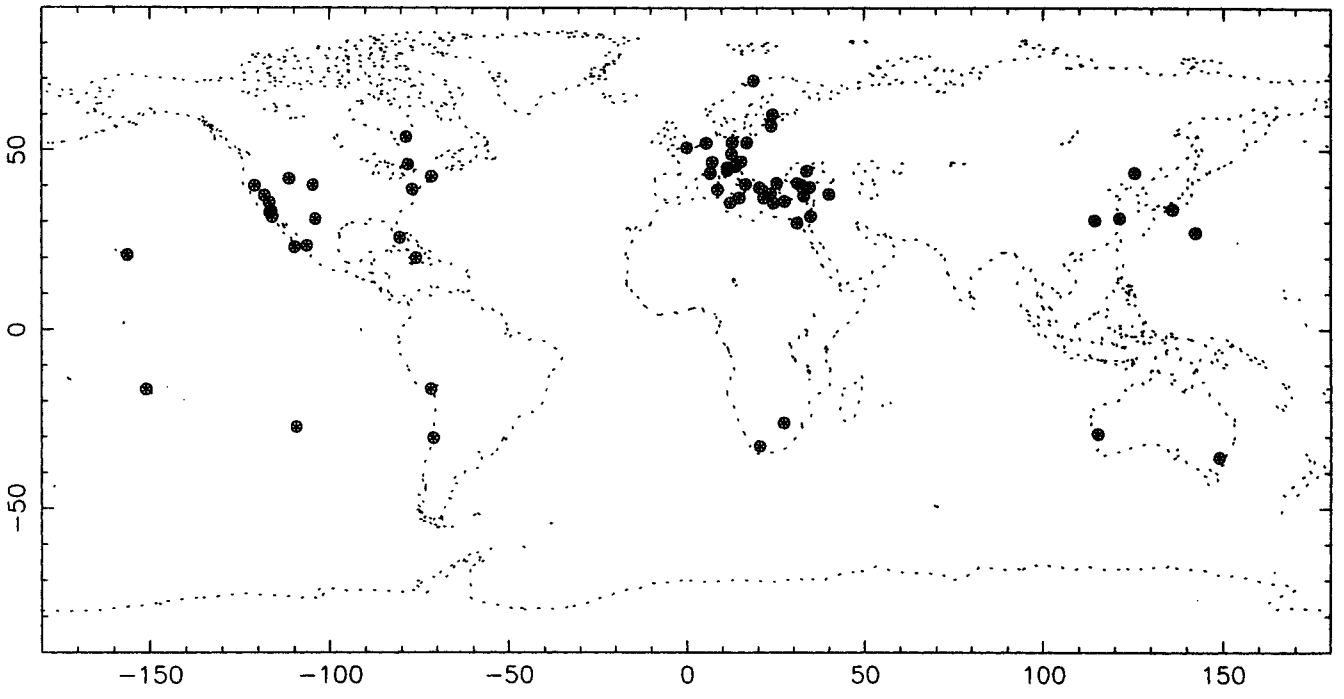
DeMets, C., Gordon, R.G., Argus, D.F., and Stein, S., 1990: Current plate motions, *Geophys. J. Int.*, **101**, 425-478.

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

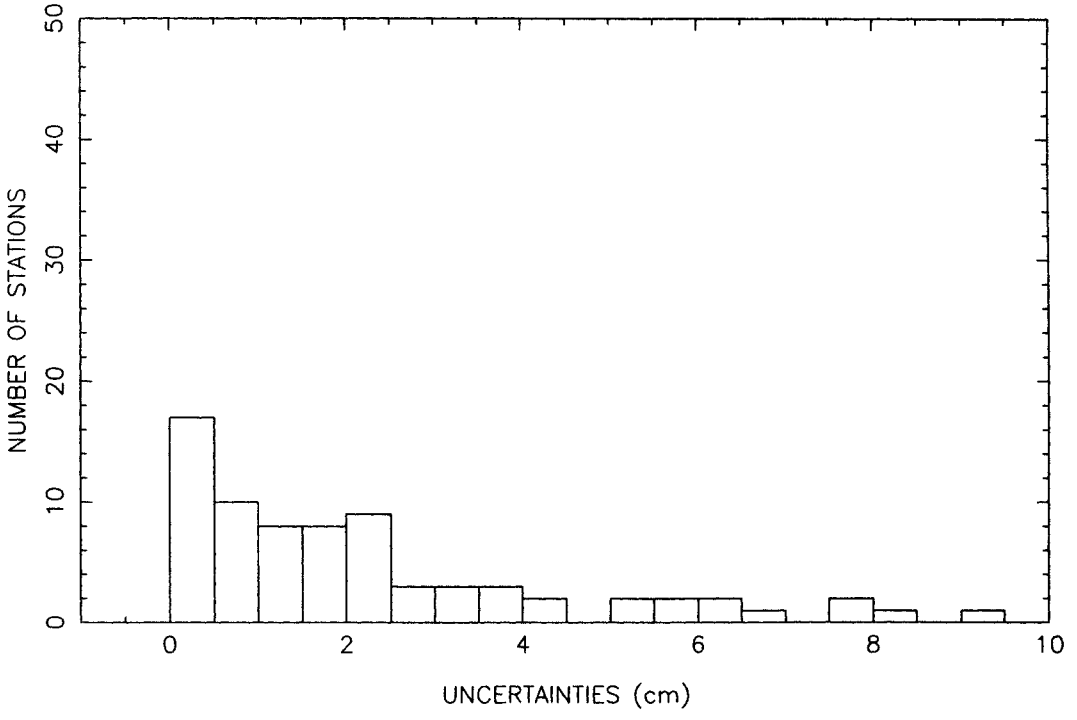
Montag, H., Reigber, Ch., Sommerfeld, W., Dick, G., 1994: Station coordinates and Earth rotation parameters based on Lageos laser ranging data, *IERS Technical Note 17,* P. Charlot, (ed.), Observatoire de Paris, Paris, L25-L30.

Technical description of solutions GFZ 95 L 01 and L 02

1 - Technique:	SLR
2 - Analysis Centre:	GeoForschungsZentrum (GFZ)
3 - Software used:	EPOS.P.V1
4 - Data span:	Nov 79 - Aug 94 for EOP Jan 86 - Aug 94 for new SSC
5 - Celestial Reference Frame:	
a - Nature:	Dynamical, LAGEOS-1 and LAGEOS-2.
b - Definition of the orientation:	By fixing the foregoing EOP series of GFZ.
6 - Terrestrial Reference Frame:	SSC(GFZ) 95 L 01
a - Relativity scale:	LE
b - Velocity of light:	299 792 458 m/s
c - Geogravitational constant:	GM = 3.986004417 10^{14} m^3/s^2 (adjusted)
d - Permanent tidal correction:	Yes
e - Definition of the origin:	C10 = 0, C11 = 0, S11 = 0.
f - Definition of the orientation:	By fixing two latitudes (7840, 7105) and one longitude (7840). Additionally no common net rotation relative to ITRF92
g - Reference epoch:	1988.0
h - Tectonic plate motion model:	Generally adjusted motions using NNR-NUVEL1 as initial model; for several sites NNR-NUVEL1 model.
i - Constraint for time evolution:	Fixed NUVEL1 plate motion model for 7840 (latitude and longitude) and 7105 (latitude).
7 - Earth Orientation:	EOP(GFZ) 95 L 01 with resolution of 5 days, EOP(GFZ) 95 L 02 with resolution of 3 days.
a - A priori nutation model:	IAU(1980), nutation corrections derived by VLBI included.
b - Short-periodic tidal variations in x, y, UT1:	Tidal variations in UT1 caused by zonal tides up to periods of 35 days considered.
8 - Estimated Parameters:	
a - Celestial frame:	
b - Terrestrial frame:	lambda0, phi0, h0, lambdadot, phidot, hdot.
c - Earth orientation:	x, y, LOD (for L 02 solution via UT1).
d - Others:	Correction to the Geogravitational constant GM; correction to the radiation pressure coefficient; along-track acceleration; range bias for single stations.



Distribution of the 63 sites of the terrestrial frame SSC(GFZ) 95 L 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 76 stations of the terrestrial frame SSC(GFZ) 95 L 01. 2 stations with uncertainties larger than 10 cm are not shown.

EOP(GFZ) 95 L 01 From Oct 1992 to Aug 1994

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for D

YEAR	X		Y		D	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	14	0.10	14	0.09	14	0.04
1993	73	0.09	73	0.08	73	0.03
1994	49	0.09	49	0.08	49	0.03

EOP(GFZ) 95 L 02 From Oct 1992 to Sep 1994

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for D

YEAR	X		Y		D	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	22	0.21	22	0.18	22	0.08
1993	122	0.14	122	0.11	122	0.04
1994	82	0.13	82	0.11	82	0.04

EARTH ORIENTATION PARAMETERS FROM GSFC SOLUTION SL8.7

GSFC 95 L 01

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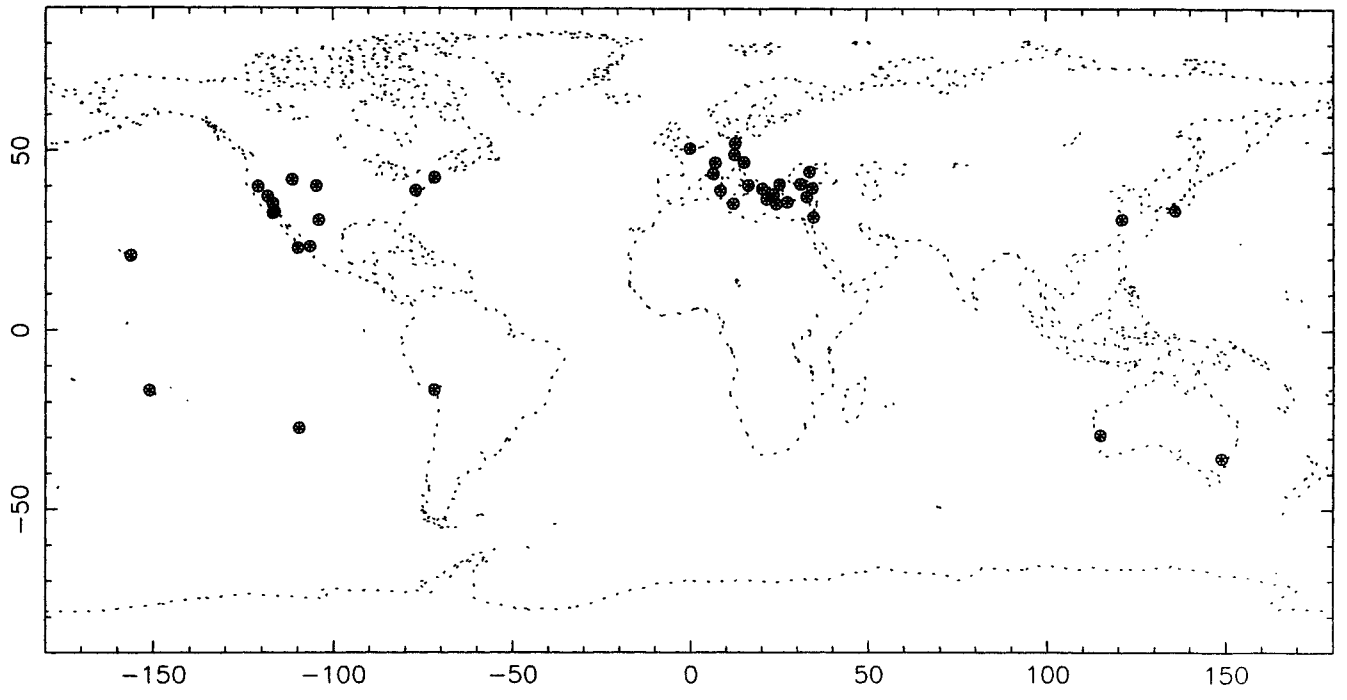
The SL8.7 solution was obtained by fitting data from LAGEOS I between January 1980 and December 1994 in 30-day (and occasionally 35-day) arcs using normal points from the global SLR tracking network. The monthly arcs were combined to derive a set of station positions at epoch 880101, and station velocities. Earth Orientation Parameters were estimated as independent values of time and polar motion at 5-day intervals from January 1980 through December 1982, and daily intervals since January 1983. Orbit and force model parameters were adjusted at the intervals indicated below. The IERS standards were followed except that the JGM3 gravity field with expanded ocean tidal terms, and a value of GM 398600.4415 km^3/s^2 were adopted.

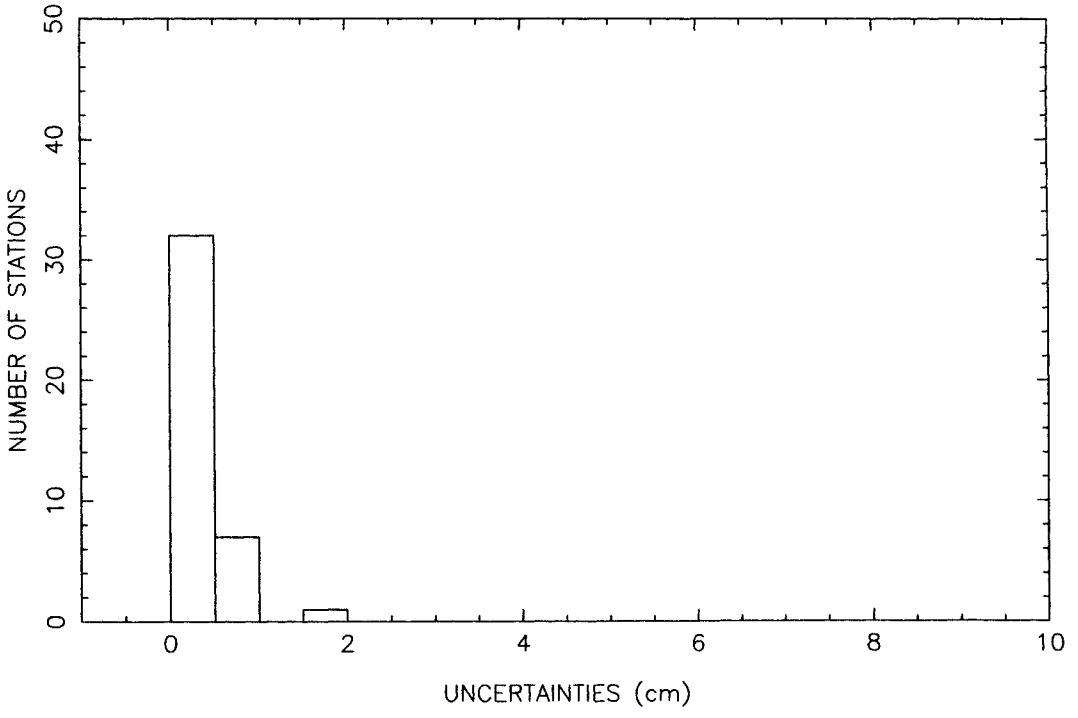
The EOP series from this solution was edited by means of a "Vondrak"-smoothing procedure using an epsilon value of 100. The resulting series are identical to the "raw" series except for the few cases where some spurious values were substituted with values interpolated from adjacent data points. This only happens when there is a lack of observations during the estimation interval; less than 4% of the data have been edited in this fashion. The LODR series were obtained from differences of the UT1R series with IERS-nodes at arc-length intervals. The forward difference was performed on the weakly smoothed UT1R series to minimize noise amplification. Examination of the RMS differences between the raw and the weakly smoothed series indicated that the smoothing did not compromise its signal content given the accuracy of the series.

Technical description of solution GSFC 95 L 01

1 - Technique:	SLR data to LAGEOS I
2 - Analysis Center:	NASA/GSFC
3 - Software used:	GEODYN II and SOLVE II
4 - Data span:	Jan 80 - Dec 94
5 - Celestial reference frame:	
a - Nature:	dynamical
b - Definition of the orientation	
6 - Terrestrial reference frame:	SSC(GSFC) 95 L 01
a - Relativity scale:	Local Earth
b -Velocity of light:	299792458 m/s
c - Geogravitational constant:	398600.4415 km^3/s^2
d - Permanent tidal correction:	yes
e - Definition of origin:	with geocenter and C10=0, C11=0, S11=0
f - Definition of orientation:	defined by fixing the latitude, longitude of Washington and latitude of Maui, and one UT1 value fixed at IERS each month
g - Reference epoch:	880101
h - Tectonic plate model:	GSFC SL8.7
i - Constraint for time evolution:	defined by fixing the latitude rate, longitude rate of Washington and latitude rate of Maui
7 - Earth orientation:	EOP(GSFC) 95 L 01
a - A priori nutation:	IAU(1980)
b - Short-period tidal variations in x, y, UT1:	modeled in UT1 as IERS (1992) standards, Chapter 10, but no short term tidal variations are modeled in the X and Y pole terms.
8 - Estimated parameters:	
a - Celestial frame:	6 elements every 30(35) days, along track acceleration twice per arc, once per revolution acceleration twice per arc.
b - Terrestrial frame:	position and velocity
c - Earth orientation:	Xp, Yp, UT1, every 5 days from 800101 to 821228, every day from 821229 to 941230.
d - Others:	



Distribution of the 40 sites of the terrestrial frame SSC(GSFC) 95 L 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 40 stations of the terrestrial frame SSC(GSFC) 95 L 01.

EOP(GSFC) 95 L 01 From Jan 1980 to Dec 1994

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1980	74	1.03	74	0.40
1981	73	0.46	73	0.27
1982	75	0.56	75	0.48
1983	360	0.70	360	0.68
1984	366	0.43	366	0.37
1985	365	0.40	365	0.35
1986	364	0.40	364	0.34
1987	365	0.33	365	0.30
1988	366	0.34	366	0.33
1989	362	0.35	362	0.32
1990	364	0.29	364	0.31
1991	363	0.40	363	0.38
1992	366	0.38	366	0.36
1993	364	0.35	364	0.34
1994	363	0.39	363	0.38

EARTH ROTATION PARAMETERS FROM LAGEOS 1 & 2 SLR OBSERVATIONS

IAA 95 L 01 - 06

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Analysis of Lageos 1 & 2 laser ranges collected from Oct 1992 (since launch of Lageos 2) till Feb 1995 have been performed. The CDDIS normal points version B from Oct 1992 till Dec 1993, normal points version A from Jan 1994 till Aug 1994, and quick look data from Sep 1994 was used. The analysis was done using GROSS (Geodynamics, earth Rotation and Orbit determination Satellite Software) that is being designed in the IAA.

The first version of GROSS had been designed on the basis of Kiev-Geodynamics-3 software (GAOUA, version for IBM/360 System). Now GROSS operates in MS DOS on PC compatible computers. Practically the whole of modules of Kiev-Geodynamics had been modified or replaced by new ones, many new programs and routines have been added. Here are control and service program, reduction of the observations, right hand sites of the equations of the motion and variation equations and so on. Differential equations are being integrated using variable step and order Adams integrator designed in the GAOUA software. Only small modifications were made in the integrator.

The observational model used in the present analysis conform to the IERS Standards recommendations with the following exceptions:

- JGM-2 geopotential coefficients are being used;
- advanced solid Earth tides models both for the site displacement and for the geopotential coefficients are being used;
- UT1R is being used instead of UT1S;
- advanced relativistic model for the satellite acceleration is being used;
- gravitation attraction of planets is being taken into account;
- effect of gravitation attraction between the Moon and non-spherical Earth is being taken into account.

Our main interest at this stage of the analysis was to choose the best strategy for daily ERP estimation. Numerous strategies were tested, six of them are proposed here for detailed comparison with results of the other institutes. The 01...05 solutions are obtained using the more or less standard strategy for most of the analysis centers. The differences between these series are as follows

- series EOP(IAA) 95 L 03 does not include adjustment of LOD;
- series EOP(IAA) 95 L 04 and EOP(IAA) 95 L 05 include adjustment of the Xp and Yp rates;
- series EOP(IAA) 95 L 05 was obtained using updated ERP at every iteration;

Series EOP(IAA) 95 L 06 was processed in another way. Testing of the standard strategy shows that results are not fully independent from initial ERP values. So, it was proposed to adjust ERP as linear spline with points at epochs of initial ERP series. This method seems to give results independent from initial values (if linear interpolation is used during calculation) but the random error is much larger than with the standard method, especially for the edges of the arcs. To allow for this effect, the mean results from overlapping arcs (1 day shift) were adopted as the final solution for this series.

The table below describes the six solutions. The length of arc was 6 days for all solutions.

Identifier	Interval	X,Y	X,Yrt	LOD	Update ERP
EOP (IAA) 95 L 01	3	x		x	
EOP (IAA) 95 L 02	1	x		x	
EOP (IAA) 95 L 03	1	x			
EOP (IAA) 95 L 04	1	x	x	x	
EOP (IAA) 95 L 05	1	x	x	x	x
EOP (IAA) 95 L 06	1	x			x

Technical description of solutions IAA 95 L 01, 02, 03, 04, 05, 06

1 - Technique: SLR

2 - Analysis Center: IAA

3 - Software used: GROSS

4 - Data span: Oct 1992 - Feb 1995

5 - Celestial Reference Frame:
- a - Nature: dynamical, Lageos 1& 2
- b - Definition of the orientation:

6 - Terrestrial Reference Frame: ITRF93, epoch 1993.0
- a - Relativity scale: LE
- b - Velocity of light: $2.99792458\ 10^8$ m/s
- c - Geogravitational constant: $3.986004418\ 10^{14}$ m^3/s^2 for two-body term $3.986004415\ 10^{14}$ m^3/s^2 for garmonics
- d - Permanent tidal correction: yes
- e - Definition of origin: C10=C11=S11=0
- f - Definition of orientation:
- g - Reference epoch:
- h - Tectonic plate model: ITRF93 velocity field used, NNR-NUVEL1 if ITRF93 not available
- i - Constraint for time evolution:

7 - Earth orientation: EOP(IAA) 95 L 01, 02, 03, 04, 05, 06
- a - A priori nutation model: IAU(1980) model with observed corrections
- b - Short-period tidal variations in x, y, UT1: included in the result series

8 - Estimated Parameters:
- a - Celestial frame:
- b - Terrestrial frame:
- c - Earth orientation: x, y, LOD
- d - Others: Satellite orbit elements, Cr every 6 days

EOP(IAA) 95 L 01 From Oct 1992 to Mar 1995

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for D

YEAR	X		Y		D	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	23	0.14	23	0.12	23	0.07
1993	122	0.13	122	0.12	122	0.07
1994	121	0.16	121	0.15	121	0.08
1995	22	0.17	22	0.18	22	0.09

EOP(IAA) 95 L 02 From Oct 1992 to Jan 1995

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for D

YEAR	X		Y		D	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	67	0.21	67	0.19	67	0.10
1993	365	0.22	365	0.19	365	0.11
1994	363	0.26	363	0.24	363	0.13
1995	30	0.27	30	0.29	30	0.12

EOP(IAA) 95 L 03 From Oct 1992 to Jan 1995

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1992	67	0.21	67	0.19
1993	365	0.22	365	0.19
1994	363	0.26	363	0.24
1995	30	0.27	30	0.27

EOP(IAA) 95 L 04 From Oct 1992 to Mar 1995

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for D

YEAR	X		Y		D	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	68	0.22	68	0.19	68	0.38
1993	365	0.23	365	0.21	365	0.48
1994	361	0.26	361	0.25	361	0.59
1995	65	0.28	65	0.31	65	0.75

EOP(IAA) 95 L 05 From Oct 1992 to Mar 1995

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for D

YEAR	X		Y		D	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	68	0.22	68	0.20	68	0.39
1993	365	0.23	365	0.21	365	0.48
1994	361	0.27	361	0.25	361	0.60
1995	65	0.29	65	0.31	65	0.74

EOP(IAA) 95 L 06 From Oct 1992 to Feb 1995

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1992	63	0.32	63	0.30
1993	365	0.30	365	0.27
1994	365	0.35	365	0.33
1995	32	0.34	32	0.33

EARTH ORIENTATION AND SITE COORDINATES BASED ON LAGEOS SLR DATA FROM THE INSTITUTE OF ASTRONOMY (RAS)

IARAS 94 L 01

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The solution IARAS 94 L 01 was computed with a new analysis program ASTRA using LAGEOS normal points data for the period August 93- July 94.

Mean positions of 20 stationary SLR sites have been adjusted to the epoch 1994.0, site velocities were held fixed to those predicted by the NNR-NUVEL1 model.

The analysis was performed in a multi-stage approach. First, the data span was divided into 5-day arcs and a satellite state vector (x, y, z, vx, vy, vz) was adjusted together with pole coordinates and LOD for each arc. Then, every set of three successive five-day arcs was combined in a 15-day arc for the estimation of the empirical coefficients Cr and Ct, which is performed simultaneously with an adjustment of the satellite state vector and EOP for the 5-day intervals. Finally, the sites coordinates, satellite state vector, pole coordinates and UT1-UTC for the middle of every 5-day arc were adjusted over the whole time period (1 year).

In this solution, corrections to nutation and sites velocities were not adjusted. They will be made when the new program ASTRA is completed.

Technical description of solution IARAS 94 L 01

1 - Technique: SLR

2 - Analysis Center: IARAS

3 - Software used: ASTRA

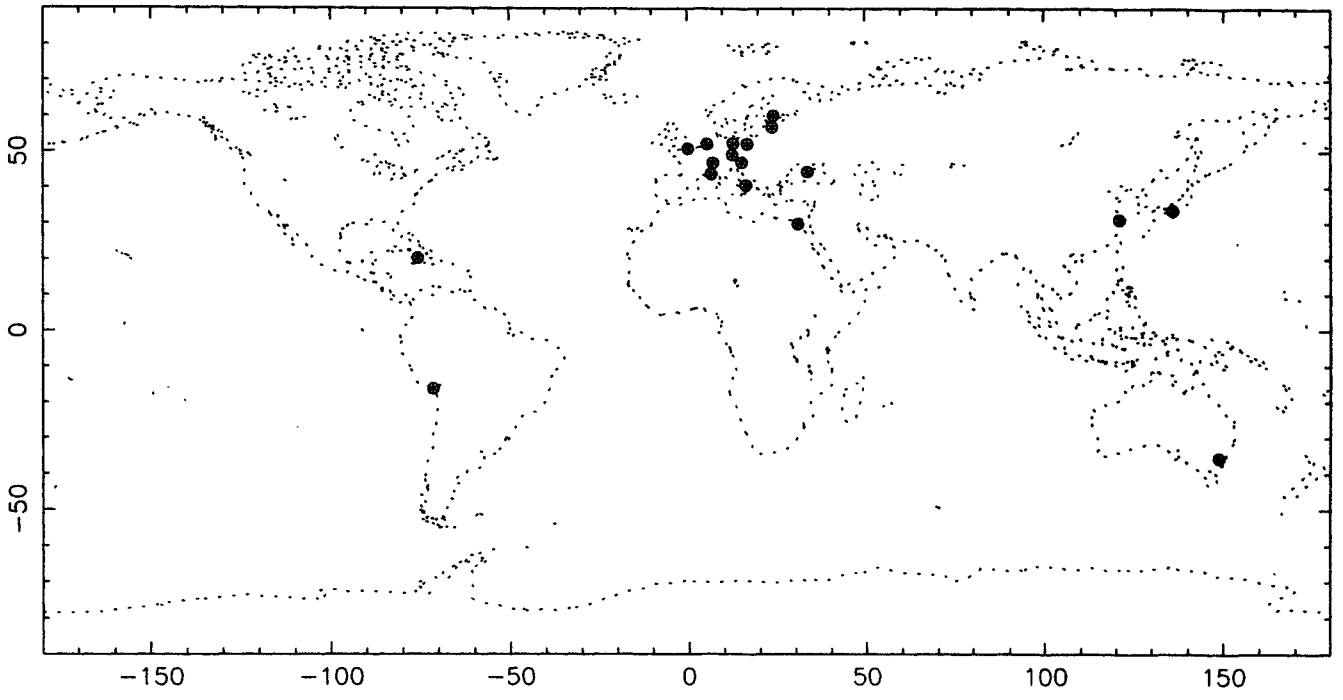
4 - Data span: Aug 93-Jul 94

5 - Celestial Reference Frame:
- a - Nature: dynamical
- b - Definition of the orientation:

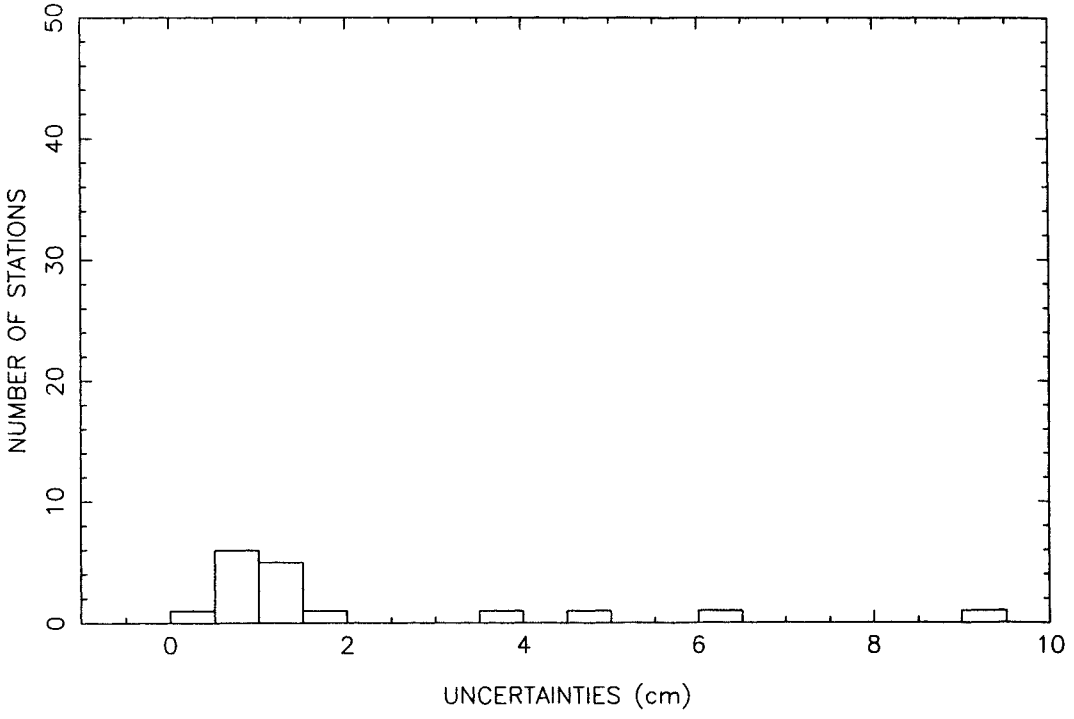
6 - Terrestrial Reference Frame: IARAS 94 L 01
- a - Relativity scale: LE
- b - Velocity of light: 2.99792 458 m/s
- c - Geogravitational constant: GMO = 3.98600441 10^{14} m^3/s^2
- d - Permanent tidal correction: No
- e - Definition of origin: C10=C11=S11=0
- f - Definition of orientation: by fixing longitude and latitude of station 7105 and latitude of station 7210, a priori EOP values from IERS Bulletin B.
- g - Reference epoch: 1994.0
- h - Tectonic plate model: NNR-NUVEL1
- i - Constraint for time evolution: fixed plate motion model

7 - Earth orientation:
- a - A priori nutation model: IAU(1980)
- b - Short-period tidal variations in x, y, UT1: the daily tidal variations in x, y, UT1

8 - Estimated Parameters:
- a - Celestial Frame:
- b - Terrestrial Frame: X0, Y0, Z0
- c - Earth Orientation: x, y, UT1-UTC
- d - Others: Cr, Ct



Distribution of the 18 sites of the terrestrial frame SSC(IARAS) 95 L 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 20 stations of the terrestrial frame SSC(IARAS) 95 L 01. 3 stations with uncertainties larger than 10 cm are not shown.

EOP(IARAS) 94 L 01 From Aug 1993 to Jun 1994

Number of measurements per year and median uncertainties
Units : 0.001" for X,Y; 0.0001s for UT1

YEAR	X		Y		UT1	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1993	31	1.60	31	1.40	31	7.00
1994	36	1.50	36	1.50	36	7.10