IERS TECHNICAL NOTE 19

Earth orientation, reference frames and atmospheric excitation functions submitted for the 1994 IERS Annual report

VLBI, LLR, GPS, SLR, DORIS and AAM Analysis Centres

P. Charlot (ed)

September 1995

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Editor: P. Charlot

IERS Technical Notes

This series of publications gives technical information related to the IERS activities, e.g. reference frames, excitation of the Earth rotation, computational or analysis aspects, models, etc. It also contains the description and results of the analyses performed by the IERS Analysis Centres for the Annual Report global analysis.

Back issues still available

No 3 : D.D. McCarthy (ed). IERS Standards (1989)

No 4 : C. Boucher and Z. Altamimi. Evaluation of the realizations of the Terrestrial Reference System done by the BIH and IERS (1984-1988).

No 7 : E.F. Arias, M. Feissel and J.-F. Lestrade. The IERS extragalactic Celestial Reference Frame and its tie with HIPPARCOS.

No 10: C. Boucher and Z. Altamimi. The IERS GPS Terrestrial Reference Frame.

No 14: P. Charlot (ed.) Earth orientation, reference frames and atmospheric excitation functions submitted for the 1992 IERS Annual Report. *[Superseded by T.N. 17]*

No 15: C. Boucher, Z. Altamimi and L. Duhem. ITRF92 and its associated velocity field

No 16: J.O. Dickey and M. Feissel (eds.). Results from the SEARCH'92 Campaign.

No 17: P. Charlot (ed.). Earth orientation, reference frames and atmospheric excitation functions submitted for the 1993 IERS Annual Report. *[Superseded by T.N. 19]*

No 18: C. Boucher, Z. Altamimi, L. Duhem. Results and Analysis of the ITRF93

No 19: P. Charlot (ed.). Earth orientation, reference frames and atmospheric excitation functions submitted for the 1994 IERS Annual Report.

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No 20: C. Boucher, Z. Altamimi, M. Feissel. Results and Analysis of the ITRF94

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ALL RESULTS DESCRIBED IN THIS ISSUE ARE AVAILABLE ON REQUEST FROM THE CENTRAL BUREAU OF IERS.

VERY LONG BASELINE INTERFEROMETRY

EARTH ROTATION AND TERRESTRIAL REFERENCE FRAME FROM VLBI DATA ANALYSIS

GAOUA 95 R 01

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Estimated values for time series of EOP and station coordinates have been determined from analysis of VLBI observations. These group delay data have been acquired by IRIS-A and NEOS-A networks since January 02, 1990 till December 27, 1994. In total 177707 dual frequency Mark III group delays with zero flag quality from 215 sessions have been processed.

The software SteelBreeze 1.01 has been used for processing VLBI observations.

This software is based on the IERS Standards (McCarthy, 1992) (models, constants) and SRIF (square root information filter) technique (Bierman, 1977) (estimation of parameters).

The initial values of station coordinates and velocities have been taken from solution SSC(IERS) 94 C 01. The obtained terrestrial reference frame has been linked to ITRF94 by requiring that the vector sum of the adjusted station coordinates be equal to the corresponding sum for the ITRF94 for a set of 8 stations (ALGOPARK, GILCREEK, KAUAI, NRAO85 3, ONSALA60, RICHMOND, WESTFORD, WETTZELL).

The initial values of radio source coordinates have been taken from solution RSC(IERS) 94 C 01.

The IAU 1980 Nutation model and initial values of EOP(IERS) 90 C 04 have been applied. The transformation between CRS and TRS has been calculated using the non-rotating origin concept (Capitaine, 1986). The tabulated daily values of EOP have been interpolated by cubic splines using 8 points. The tidal variations in UT1 have been removed from tabulated values before the splining procedure and added to interpolated ones (except for diurnal and semi-diurnal variations because they are not present in the solution EOP(IERS) 90 C 04). Then polar motion and UT1 have been corrected for diurnal and semi-diurnal tidal variations (Herring, 1993).

The orientation of the terrestrial and celestial reference frames has been defined by EOP from EOP(IERS) 90 C 04 (with linear transformations to be consistent with ITRF94 and ICRF94) for the EOP reference date August 12, 1991.

Tropospheric refraction in the local zenith direction caused by hydrostatic and water vapour components of the neutral atmosphere have been modelled according to Saastamoinen (1972). The zenith delays have been mapped to line of sight elevations with the MTT mapping function of Herring (1992) for both hydrostatic and wet components.

The ionospheric component has been eliminated by using simultaneous dual frequency observations.

Calibration data collected at each observing site have been applied to correct for variations in the electrical length of the cables between the radio receivers and the data acquision systems.

The wet zenith delay and clock offset have been estimated as stochastic processes and modelled as random walk with following magnitudes of power spectral density of ruled white noise: for clock offset 20^2 ps^2/hour, for wet component of tropospheric delay 1.0 cm^2/hour.

The weighted rms post-fit residuals of this solution is 29.04 ps in delay.

Acknowledgments

This work has been done during a stay of the author at the Observatory of Paris and was supported by long-term visitor support at the Observatory of Paris. Also it was partly supported by the International Science Foundation under grant U4S000.

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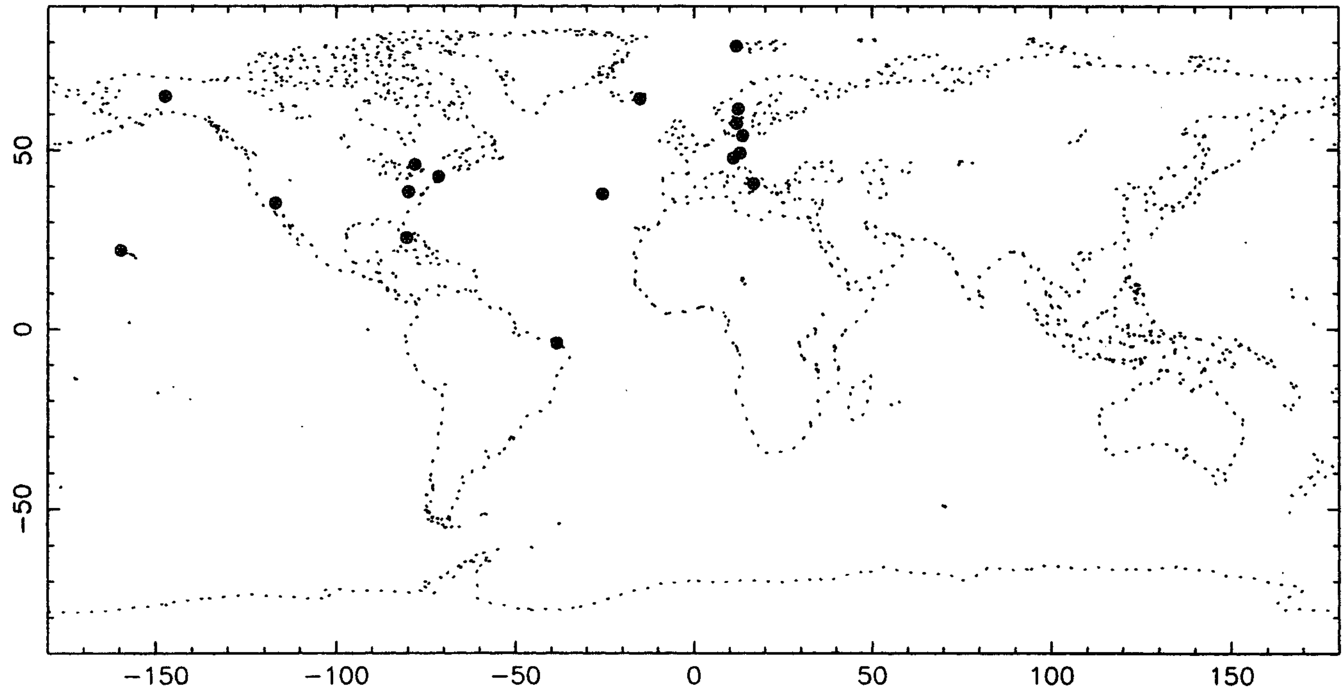
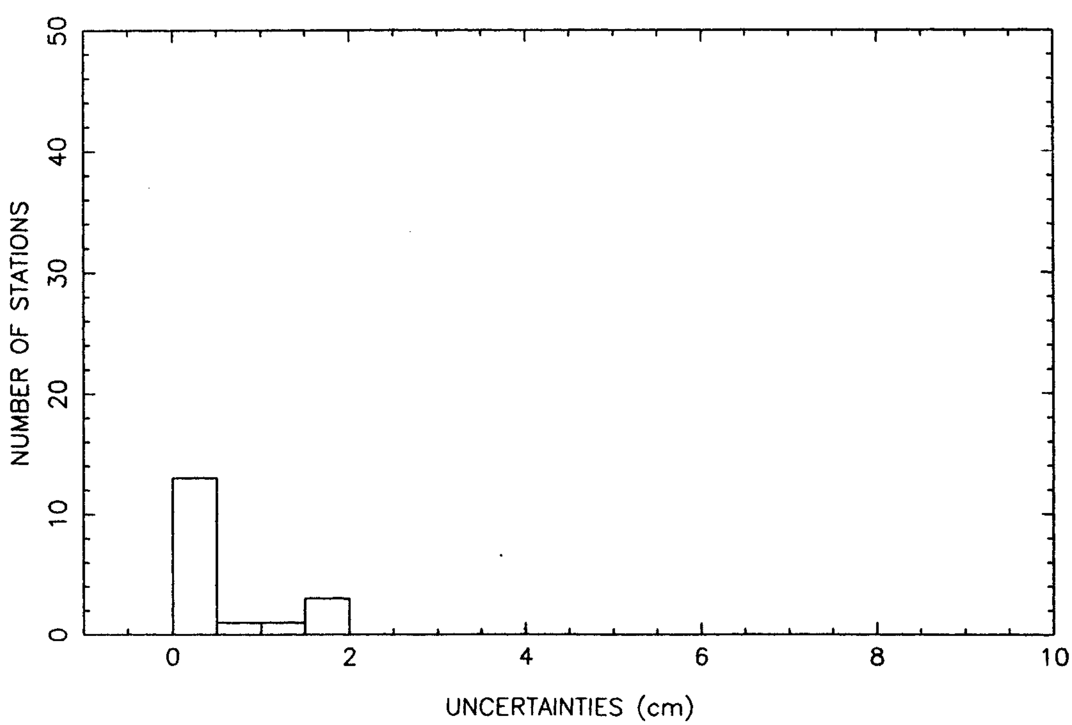
Technical description of solution GAOUA 95 R 01

1 - Technique:	VLBI
2 - Analysis Center:	GAOUA
3 - Software used:	SteelBreeze 1.01
4 - Data span:	Jan 1990 - Dec 1994
5 - Celestial Reference Frame:	RSC(IERS) 94 C 01
a - Nature:	
b - Definition of the orientation:	
6 - Terrestrial Reference Frame:	SSC(GAOUA) 95 R 01
a - Relativity scale:	SSB
b - Velocity of light:	299792458 m/s
c - Geogravitational constant:	not applicable
d - Permanent tidal correction:	no
e - Definition of origin:	by using no-translation constraint for 8 VLBI stations
f - Definition of orientation:	by fixing EOP values at Aug 12, 1991 equal to EOP(IERS) 90 C 04
g - Reference epoch:	1993.0 (MJD 48988)
h - Tectonic plate model:	set of velocities from SSC(IERS) 94 C 01
i - Constraint for time evolution:	no
7 - Earth orientation:	EOP(GAOUA) 95 R 01
a - A priori nutation model:	IAU 1980 + corrections EOP(IERS) 90 C 04
b - Short-period tidal variations in x, y, UT1:	according to Herring (1993). Corrections added to EOP(IERS) 90 C 04. EOP(GAOUA) 95 R 01 does not contain diurnal and semidiurnal tidal variations
8 - Estimated Parameters:	
a - Celestial Frame:	no
b - Terrestrial Frame:	X0, Y0, Z0
c - Earth Orientation:	Xp, Yp, UT1-UTC, $\delta\psi$, $\delta\varepsilon$
d - Others:	wet zenith tropospheric delays and station clock offset at each site of observation as stochastic parameters



Distribution of the 17 sites of the terrestrial frame SSC(GAOUA) 95 R 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 18 stations of the terrestrial frame SSC(GAOUA) 95 R 01.

EOP(GAOUA) 95 R 01 From Jan 1991 to Dec 1994

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

YEAR	X		Y		UT1		$\delta\psi$		$\delta\epsilon$	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
1991	58	0.14	58	0.15	58	0.07	58	0.21	58	0.08
1992	52	0.20	52	0.20	52	0.08	52	0.30	52	0.13
1993	52	0.13	52	0.12	52	0.05	52	0.22	52	0.09
1994	52	0.11	52	0.09	52	0.05	52	0.18	52	0.08

EARTH ORIENTATION PARAMETER DETERMINATIONS AT THE GEODETIC INSTITUTE OF THE UNIVERSITY OF BONN

GIUB 95 R 01

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The VLBI group at the Geodetic Institute of the University of Bonn (GIUB) has analysed VLBI experiments which are organized within project IRIS-S (International Radio Interferometric Surveying - South), with the German Antarctic station O'Higgins and within the European geodetic VLBI project. The IRIS-S observations form the backbone of the analyses for Earth orientation and terrestrial reference frame determinations. Until the end of 1994, 83 experiments were observed with a network of stations which is grouped around the Wettzell (Germany) - Westford (US East Coast) - HartRAO (Hartebeesthoek Radio Astronomy Observatory, South Africa) baseline triangle. Today the network is formed by the stations of Wettzell, HartRAO, Westford and Fortaleza (Brazil).

The IRIS-S as well as all other sessions included in the final solution are analyzed using the CALC 8.1/SOLVE/GLOBL software system (Gordon 1994). The theoretical delays in the adjustment are calculated according to the Consensus model (Eubanks, 1991).

The apriori EOP values for each observation are calculated by linearly interpolating the USNO Rapid Service Series and subsequently applying corrections for diurnal and semidiurnal tidal variations of polar motion and UT1. The corrections are modelled using the Wünsch and Busshoff (1992) amplitudes for UT1 scaled by 1.13 to subtract the equatorial moment of inertia of the core and the Seiler and Wünsch (in preparation) amplitudes for polar motion (see Technical Description). The Seiler and Wünsch model of ocean tidal variations in polar motion is an extension of the Brosche and Wünsch (1994) model that takes into account the resulting polar motion of the angular momentum balance of the oceans for a hydrodynamical numerical ocean model. The extension includes 20 additional tides in the diurnal and semidiurnal tidal band.

Additional VLBI data is acquired within the European geodetic VLBI project and within activities closely related to the German ERS/VLBI station O'Higgins in Antarctica. The station of O'Higgins has successfully observed three bursts of four experiments each with southern hemisphere networks consisting of the stations of Santiago (Chile), Hobart (Tasmania, Australia), DSS45 (NASA Complex Tidbinbilla, Australia) and HartRAO. These experiments contribute a number of precise source positions in the deep south.

Since 1990 the European VLBI stations of Wettzell, Onsala (Sweden), Madrid (Spain), Medicina, Matera and Noto (all Italy) have been performing geodetic VLBI experiments for the determination of European tectonic motions on a regular basis. More recently the telescopes at Effelsberg (Germany), Ny Alesund (Spitsbergen, Norway) and Simeiz on the Crimea peninsula (Ukraine) have been participating in several experiments extending the number of stations with highly accurate positions on the European continent.

In a combined solution (GIUB 95 R 01) all IRIS-S measurements, 21 European sessions and 11 experiments of the O'Higgins bursts are adjusted in a single least squares adjustment solving for station coordinates and radio source positions as global parameters as well as EOP and celestial pole offsets. In order to stabilize the European subnet within the global frame of the IRIS-S network we also added the data of two 1994 South Atlantic sessions of the NASA Goddard Space Geodesy Program to the solution which includes observations between Madrid and the South American stations.

The origin of the terrestrial reference frame is fixed through the Wettzell station coordinates which are kept at the ITRF 1992 (IERS, 1993b) values applying drift effect corrections according to the NNR-NUVEL1A model (DeMets *et al.*, 1994).

For the estimation of station displacement parameters the global kinematics of the network has to be defined by fixing an additional set of six degrees of freedom. This is achieved by modelling the tectonic station displacement of Wettzell according to the NNR-NUVEL1A model, constraining the change of the direction of the Westford to Wettzell baseline vector to the same model, and fixing the height changes of HartRAO to zero. Using the direction of the Westford to Wettzell baseline as a definition for the long term displacement of the terrestrial reference frame bears two advantages. The first is that this long baseline reduces the effects of inaccuracies in the individual sessions. The second is that possible inaccuracies in the model of a single tectonic plate do not so strongly affect the long term orientation of the network with respect to the axis of rotation. The origin of right ascension is fixed by the ICRF 1992 position of OJ287 (IERS, 1993a).

The European sessions are treated slightly differently since the comparably small extension of the network reduces the sensitivity for Earth orientation parameter determinations. Thus the inclusion of the European sessions mainly aims at the determination of station coordinates and displacement vectors for the terrestrial reference frame. In order to stabilize the solution weak constraints of 15 mas are introduced for the pole components and UT1-UTC estimated with data of these sessions.

Since the data gathered at some of the stations are limited or the time span is not long enough for a reliable estimation of station displacement parameters, drift components are modelled according to NNR-NUVEL1A for some of the stations while vertical drift rates are constrained to zero for most of the others. Since the data of Mojave cover only 2.5 years in our analysis no provision is made for any episodic movements detected in longer data sets.

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Technical description of solution GIUB 95 R 01

1 - Technique:	Mark III VLBI, Group delay observables
2 - Analysis Center:	Geodetic Institute of the University of Bonn (GIUB), Nussallee 17, D-53115 Bonn, Germany
3 - Software used:	CALC 8.1, SOLVE/GLOBL
4 - Data span:	Jan 86 - Dec 94 (irregular intervals)
5 - Celestial Reference Frame:	RSC(GIUB) 95 R 01
a- Nature:	extragalactic
b- Definition of the orientation:	RA of OJ287 fixed to ICRF 1992 and nutation at Dec 22, 1989 fixed to IAU 1980
6 - Terrestrial Reference Frame:	SSC(GIUB) 95 R 01
a- Relativity scale:	SSB
b- Velocity of light:	299 792 458 m/s
c- Geogravitational constant:	Not applicable
d- Permanent tidal correction:	No
e- Definition of origin:	Wettzell fixed at ITRF 1992
f- Definition of orientation:	EOP at Dec 22, 1989 fixed to IERS RS
g- Reference epoch:	1988.0
h- Tectonic plate model:	NNR-NUVEL1A
i- Constraint for time evolution:	Reference station Wettzell moves according to NNR-NUVEL1A, baseline direction Wettzell to Westford moves according to NNR-NUVEL1A, HartRAO height changes are constrained to zero
7 - Earth Orientation:	EOP(GIUB) 95 R 01
a- A priori nutation model:	IAU(1980)

b- Short period tidal variations in x, y, UT1:

UT1 tidal terms

l	l'	F	D	Om	GST +π	Tide	A1-Amplitude [microtimesec]	A2-Amplitude [microtimesec]
0	0	0	0	0	-1	K1	14.64	11.48
0	0	2	-2	2	-1	P1	-6.09	-3.65
0	0	2	0	2	-1	O1	-12.90	-32.10
0	0	2	-2	2	-2	S2	-3.58	18.25
0	0	2	0	2	-2	M2	-23.34	27.14
1	0	2	0	2	-2	N2	-4.75	5.93

Polar motion tidal terms

l	l'	F	D	Om	GST +π	Tide	A1-Amplitude [microarcsec]	A2-Amplitude [microarcsec]
0	0	2	0	1	1	to OO1 p	5.28	-2.64
0	0	2	0	2	1	OO1 p	8.22	-4.13
1	0	0	0	0	1	J1 p	9.31	-2.32
0	0	0	0	-1	1	to K1 p	20.10	-8.95
0	0	0	0	0	1	K1 p	160.18	-65.37
0	0	-2	2	-2	1	P1 p	-50.44	21.93
0	-1	-2	2	-2	1	Pi1 p	-2.86	1.43
-1	0	0	0	0	1	M1 p	10.53	-5.09

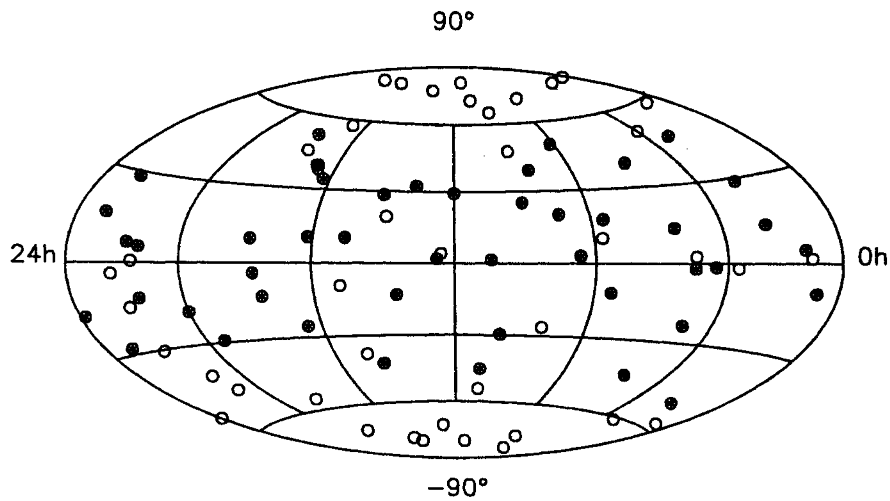
Polar motion tidal terms (continued)

l	l'	F	D	Om	GST +π	Tide	A1-Amplitude [microarcsec]	A2-Amplitude [microarcsec]
1	0	-2	0	-2	1	to O1 p	3.77	-1.85
0	0	-2	0	-2	1	O1 p	-177.50	38.38
0	0	-2	0	-1	1	to O1 p	-31.75	5.94
1	0	-2	-2	-2	1	Rho1 p	-6.29	0.40
-1	0	-2	0	-2	1	Q1 p	-33.38	1.22
-1	0	-2	0	-1	1	to Q1 p	-6.39	0.30
0	0	-2	-2	-2	1	Sigma1 p	-5.79	-0.32
0	0	0	0	1	-2	to K2 r	0.63	18.89
0	0	0	0	0	-2	K2 r	-0.78	63.70
0	0	2	-2	2	-2	S2 r	-64.02	227.65
0	1	2	-2	2	-2	T2 r	2.38	12.58
-1	0	2	0	2	-2	L2 r	-3.11	9.29
0	0	2	0	2	-2	M2 r	164.97	258.94
0	0	2	0	1	-2	to M2 r	3.13	6.04
1	0	2	2	2	-2	Ny2 r	0.41	8.79
1	0	2	0	2	-2	N2 r	15.66	35.95
0	0	2	2	2	-2	My2 r	2.27	5.56
2	0	2	0	2	-2	2N2 r	1.56	4.54
0	0	0	0	-1	2	to K2 p	0.10	-3.30
0	0	0	0	0	2	K2 p	-0.50	-10.69
0	0	-2	2	-2	2	S2 p	-11.65	-29.45
0	-1	-2	2	-2	2	T2 p	0.39	-2.47
1	0	-2	0	-2	2	L2 p	-0.79	2.37
0	0	-2	0	-2	2	M2 p	26.88	-103.40
0	0	-2	0	-1	2	to M2 p	1.82	-3.22
-1	0	-2	-2	-2	2	Ny2 p	2.25	-3.19
-1	0	-2	0	-2	2	N2 p	12.32	-18.26
0	0	-2	-2	-2	2	My2 p	3.99	-0.29
-2	0	-2	0	-2	2	2N2 p	2.89	0.24

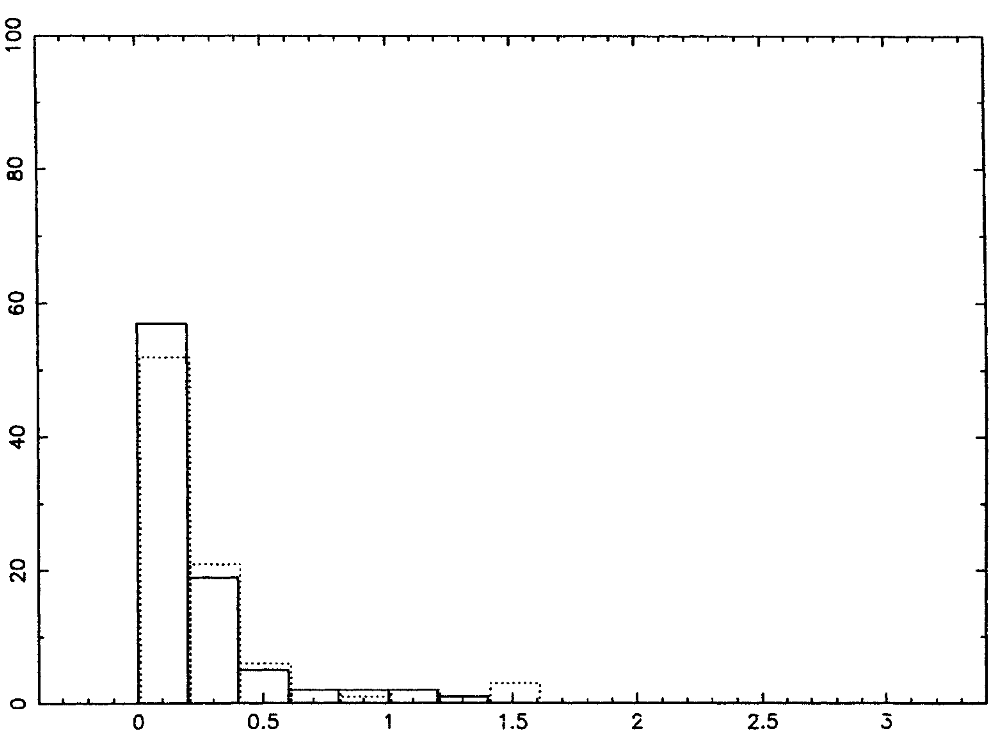
p = prograde, r = retrograde
Terms are included in the EOP reported to IERS

8 - Estimated Parameters:

a- Celestial frame:	right ascensions (except OJ287) and declinations
b- Terrestrial frame:	station coordinates (x,y,z) of all stations except Wettzell; linear horizontal velocities (Ldot, Pdot expressed as xdot, ydot, zdot) of HartRAO, DSS65, Noto, Effelsberg, Richmond and Mojave; linear velocities (xdot, ydot, zdot) of Onsala, Matera and Medicina;
c- Earth Orientation:	xp, yp, UT1-UTC, $\delta\psi$, $\delta\varepsilon$, (xp, yp and UT1-UTC of European sessions are constrainted by 15 mas)
d- Others:	clock polynomials, wet zenith tropospheric delays



Distribution over the sky of the 89 extragalactic radio sources of the celestial frame RSC(GIUB) 95 R 01. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(GIUB) 95 R 01. 1 radio source with uncertainty larger than 0.003" is not shown.

EOP(GIUB) 95 R 01 From Jan 1986 to Dec 1994

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

YEAR	X		Y		UT1		$\delta\psi$		$\delta\epsilon$	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
1986	6	0.50	6	0.36	6	0.39	6	0.65	6	0.27
1987	8	0.42	8	0.31	8	0.39	8	0.51	8	0.22
1988	5	0.42	5	0.31	5	0.53	5	0.52	5	0.24
1989	6	0.45	6	0.30	6	0.26	6	0.59	6	0.29
1990	14	0.36	14	0.27	14	0.19	14	0.51	14	0.23
1991	15	0.35	15	0.27	15	0.18	15	0.46	15	0.21
1992	18	0.38	18	0.28	18	0.22	18	0.47	18	0.21
1993	23	0.46	23	0.31	23	0.21	23	0.48	23	0.21
1994	22	0.55	22	0.38	22	0.24	22	0.51	22	0.22

SITE POSITIONS AND VELOCITIES, SOURCE POSITIONS, AND EARTH ORIENTATION PARAMETERS FROM THE NASA SPACE GEODESY PROGRAM-GSFC: SOLUTION GLB979F

GSFC 95 R 01

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Mark III VLBI delay data acquired between Aug. 1979 and Dec. 1994 have been analyzed for the terrestrial and celestial reference frames. The sessions used for GLB979f (GSFC 95 R 01) include all geodetic and astrometric VLBI sessions available to the NASA Space Geodesy Program-GSFC except for the data acquired by the NASA Deep Space Network (DSN) for spacecraft navigation. An alternate celestial frame solution which includes also the DSN data (RSC(GSFC) 95 R 02) has been calculated as well.

The major differences from previous submissions include the use of CALC 8.1, changes in some axis offsets, and three new permanent stations: Urumqi (China), Crimea (Ukraine), and Ny Alesund (Spitzbergen). The solid Earth tide model in CALC 8.1 and the ocean loading coefficients have been made fully consistent with the 1992 IERS standards. The axis offset model has been improved. The axis offset values at GILCREEK and HARTRAO were updated using new surveys that are consistent with estimates from VLBI. The axis offset of USSURISK was updated from a VLBI estimate. Only delay observations were used in this work. The number of sites used to constrain the time evolution of the TRF was reduced from eight to five. The sites eliminated (KAUAI, GILCREEK, and ONSALA60) show small but formally significant departures from the underlying NNR NUVEL-1 plate motion model. UT1 values are reported for IRIS and NAVNET intensive sessions.

The basic models used to calculate the VLBI delays are consistent with the 1992 IERS standards and are contained in the Goddard CALC 8.1 program. These include IAU 1980 nutation with daily offsets in longitude and obliquity estimated, solid Earth tides correcting the K1 term but not the zero frequency displacement, pole tide, vertical and horizontal ocean loading, DE200 solar system ephemeris, and a modified Hellings (1986) VLBI time delay that agrees with the IERS standard model within 5 ps rms. The pole position for each observation was interpolated linearly from a one-day input series. The UT1 value for each observation was derived from the one-day series by first removing the IERS standard UT1R tidal model, interpolating linearly to the epoch of observation, then restoring the standard tidal model. In addition, diurnal and semidiurnal EOP variations (derived from a subset of the Mark III geodetic data) were added to the interpolated pole and UT1 values.

The GLB979f solution was constructed in several steps using an incremental solution and arc-parameter elimination (Ma *et al.*, 1990). First the sessions comprising large networks and strong data as well as the single baseline POLARIS days (2106 sessions, 1354582 delays) were combined to form a preliminary TRF using the modified one-day EOP(IERS) 90 C 04 values as a priori input. The adjusted parameters included site positions and velocities, source positions, EOP values, UT1 rates, nutation offsets, and clock and troposphere parameters. Weak EOP constraints (45 mas and 3 ms for X/Y pole and UT1, respectively) were applied so that all three EOP components could be estimated for single baseline sessions with reliable indication of uncertainty and correlation. The EOP values, UT1 rates, and their covariances from each day were then input to a simple Kalman filter to generate a one-day VLBI EOP series. The covariances and interpolated EOP values from this series were used as a priori information when the solution was incremented with the remaining full-day data (308 sessions, 108190 delays), largely mobile and small network sessions. Finally the reported EOP and nutation offset values were generated from a back solution using weak EOP constraints for all the sessions. While EOP values are given for all sessions, a flag indicates which values are useful. UT1 values from the 1-hr, single baseline, daily IRIS intensive measurements were generated from a back solution using pole position values, nutation offsets, and their respective covariances from the GLB979f solution. Similarly, the EOP values from the 2 and 3-hr, three-baseline NAVNET intensive measurements came from a back solution using nutation offset and covariance information from the GL979f solution.

About 220 sources used largely in the geodetic programs form the core of the celestial reference frame. These have ~100 to ~100000 observations each. About 450 sources have 1-sigma formal errors under 1 mas while ~300 have formal errors under 0.3 mas. The remaining sources include a number with weak data. Sources with uncertainties >10 mas are not reported. While the terrestrial reference frame has more than 120 points, the distribution of data temporally and spatially is very uneven. The southern hemisphere has only five stations. Some of the best stations, notably the VLBA, only began observing in recent years, and their positions at the reference epoch 1988.0 is not representative. The median 1-sigma formal errors in the horizontal and vertical position components at the best epoch for each site are 2 mm and 7 mm, respectively. More than half the sites have useful velocity estimates, and the median horizontal and vertical rate errors are 0.5 mm/yr and 2 mm/yr, respectively.

In total 1466561 dual-frequency Mark III delays from 2415 full-day sessions are included in solution GLB979f. The solution has 1997 global parameters and 495627 arc parameters with 1135300.8 degrees of freedom. The weighted rms post-fit delay residual of the solution is 35.4 ps. The reduced chi-square is 1.019 including the constraints for the wet troposphere, clocks, and EOP in the computation of the degrees of freedom (Theil, 1963). The statistics for the IRIS and NAVNET intensives are 2356 sessions and 22267 delays with 23.5 ps wrms residual and 119 sessions and 4146 delays with 30.8 ps wrms residual, respectively.

The site coordinates and velocities at 1988.0 are designated SSC(GSFC)95 R 01. Other results are three Earth orientation time series designated EOP(GSFC)95 R 01 for the full-day data, EOP(GSFC)95 R 02 for the IRIS intensive data, and EOP(GSFC)95 R 03 for the NAVNET intensive data. The source positions are designated RSC(GSFC)95 R 01.

References

Hellings, R. W., 1986: *Astron. J.*, **91**, 1446.

Ma, C., Sauber, J. M., Bell, L. J., Clark, T. A., Gordon, D., Himwich, W. E. and Ryan, J. W., 1990: *J. Geophys. Res.*, **95**, 21991.

Theil, H., 1963: *Amer. Stat. Ass. J.*, **58**, 401.

Technical description of solution GSFC 95 R 01

1 - Technique:	VLBI
2 - Analysis Center:	Goddard Space Flight Center
3 - Software used:	CALC 8.1, SOLVE/GLOBL
4 - Data span:	Aug 79 - Dec 94
5 - Celestial Reference Frame:	RSC(GSFC) 95 R 01
a - Nature:	extragalactic
b - Definition of the orientation:	The celestial reference frame orientation is defined by the CEP pole position computed from the IAU 1980 nutation model and the J2000.0 precession model for the 1993 Sep 30 reference day corrected by the nutation offset

from the modified EOP(IERS) 90 C 04 series and by the ICRF92 right ascension of 2145+067.

6 - Terrestrial Reference Frame: SSC(GSFC) 95 R 01

a - Relativity scale: SSB from modified Hellings VLBI delay model

b - Velocity of light: 299 792 458 m/s

c - Geogravitational constant: not applicable

d - Permanent tidal correction: No permanent tide applied

e - Definition of origin: The origin of the terrestrial reference frame is set by minimizing the Cartesian adjustments of nine stations (WESTFORD, RICHMOND, GILCREEK, KAUAI, HOBART26, DSS45, HARTRAO, WETTZELL, ONSALA60) with respect to ITRF92 at 1988.0.

f - Definition of orientation: The orientation of the terrestrial reference frame is defined by the a priori EOP values on the reference day (1993 Sep 30) from the modified EOP(IERS) 90 C 04 series that is consistent with ITRF92 (M. Feissel, private communication).

g - Reference epoch: 1988.0

h - Tectonic plate model: NNR-NUVEL1

i - Constraint for time evolution:

The horizontal rate residuals of five stations (WESTFORD, RICHMOND, HOBART26, DSS45, WETTZELL) with respect to No-Net-Rotation NUVEL1 are minimized. The adjusted vertical rates of the same stations are also minimized. The stations with insufficient data or time interval are constrained to move with NNR-NUVEL1 with uncertainties in vertical, east and north rates of 0, 3, and 3 mm/yr, respectively. These stations are:

OCOTILLO, GOLDMARS, PARKES, TIDBIN64, MADRID64, SEST, VLA,VICTORIA, MIZNAO10, CHLBOLTN, USSURISK, TITIJIMA, MIYAZAKI, DAITO, URUMQI, CRIMEA, NYALES20, MIZUSGSI, SAGARA, AUSTINTX, CARROLGA, BERMUDA, SINTOTU, USUDA64, MILESMON, BLOOMIND, LEONRDOK, BREST, CARNUSTY, METSHOVI, HOHENFRG, GRASSE, HOFN, KARLBURG, TOULOUSE, AZORES, HOHNBERG, KIRSBERG.

The vertical rates for stations that had uncertainties in their vertical rates in excess of 3mm/yr in an unconstrained solution are also constrained to zero. These stations are:

MON_PEAK, HN-VLBA, MK-VLBA, PLATTVIL, GORF7102, GGAO7108, SANTIA12, QUINCY, DSS15, TSUKUBA, PT_REYES, SC-VLBA, KWAJAL26, PINFLATS, PRESIDIO JPL_MV1, NOME, MARCUS, TROMSONO, YUMA, FORT_ORD, FORTORDS, ELY, FLAGSTAF, KODIAK, VERNAL, PBLOSSOM, SNDPOINT, PENTICTN, SANPAULA, PVERDES, BLKBUTTE, TRYSILNO, SOURDOGH, YAKATAGA, SEATTLE1, MAMMOTHL OHIGGINS WHTHORSE DEADMANL, NOBEY_6M.

The velocities of the following groups of sites are constrained to be identical:

DSS65-ROBLED32, SESHAN25 - SHANGHAI, FORT ORD - FORTORDS, MOJAVE12-MOJ 7288, OVRO 130 - OVR 7853, ONSALA60 - MV2ONSLA - ONSALA85, NRAO 140-NRAO85 1, KAUAI - KOKEE - HALEAKAL, YELLOWKN - YLOW7296, GORF7102 - GGAO7108, HRAS 085 - FTD 7900 - MCD 7850.

The positions of the following sites were allowed to change discontinuously once:

YAKATAGA (871201), SOURDOGH (871201), WHTHORSE (871201), FORTORDS (891001), PRESIDIO (891001), NRAO85 3 (901201), MOJAVE12 (920627), DSS15 (920627).

7 - Earth orientation: EOP(GSFC) 95 R 01
a - A priori nutation model: IAU(1980)
b - Short-period tidal variations in x, y, UT1: Diurnal and semidiurnal tidal variations in polar motion and UT1 were estimated using geodetic VLBI data (10 tidal components in UT1 and 12 in polar motion). The model below is applied in this solution. The variations are included in the reported EOP series.

UT1 tidal terms (microseconds)

l	l'	F	D	Om	GST +pi	term	Cos	Sin
0	0	0	0	0	-1	K1	6.252927	15.600300
0	0	2	-2	2	-1	P1	-2.649379	-5.246193
0	0	2	0	2	-1	O1	-15.381776	-15.592820
1	0	2	0	2	-1	Q1	-3.534252	-4.015490
0	1	0	0	0	-1	S1	-.369238	1.106177
1	0	0	0	0	-1	M1	1.220679	1.882189
0	0	0	0	0	-2	K2	-.071600	3.800587
0	0	2	-2	2	-2	S2	-1.043297	8.605459
0	0	2	0	2	-2	M2	-10.846194	14.708632
1	0	2	0	2	-2	N2	-2.514309	3.199383

Polar motion tidal terms (microarcseconds)

l	l'	F	D	Om	GST +pi	term	Cos	Sin
0	0	0	0	0	1	P K1	128.996879	-47.392242
0	0	-2	2	-2	1	P P1	-48.638393	28.332852
0	0	-2	0	-2	1	P O1	-132.971705	68.974209
-1	0	-2	0	-2	1	P Q1	-33.869221	11.177365
0	0	0	0	0	-2	R K2	-15.297337	15.916971
0	0	2	-2	2	-2	R S2	-74.696652	108.377915
0	0	2	0	2	-2	R M2	-3.221247	273.078222
1	0	2	0	2	-2	R N2	-4.989908	41.822294
0	0	0	0	0	2	P K2	11.645893	-10.680081
0	0	-2	2	-2	2	P S2	-10.393208	-15.655399
0	0	-2	0	-2	2	P M2	16.337510	-57.620809
-1	0	-2	0	-2	2	P N2	2.330556	-15.138890

P = Prograde, R = Retrograde

Earth orientation: EOP(GSFC) 95 R 02 - IRIS intensive sessions
a - A priori nutation model: EOP(GSFC) 95 R 01
b - Short-period tidal variations in x, y, UT1: same as above

Earth orientation: EOP(GSFC) 95 R 03-USNO intensive sessions
a - A priori nutation model: EOP(GSFC) 95 R 01
b - Short-period tidal variations in x, y, UT1: same as above

8 - Estimated Parameters:
a - Celestial Frame: right ascension except 2145+067, declination

b - Terrestrial Frame:	X0, Y0, Z0, Xdot, Ydot, Zdot
c.- Earth Orientation:	x, y, UT1-TAI, UT1dot, $d\psi$, $d\varepsilon$
d - Others:	Piece-wise linear, continuous wet zenith troposphere delays using MTT wet mapping function Station clock offsets, rates and quadratics as well as piece-wise linear, continuous terms Clock breaks as required Baseline clock offsets

9 - Miscellaneous notes:

Only group delay observations are used.

Only observations above 7 degrees elevation are used.

EOP values are estimated at the chronological midpoint of each session rounded to the nearest minute.

The axis offsets of the following sites are modified from previous values using information from local surveys (GILCREEK, HARTRAO) and VLBI estimates:

ALGOPARK, BR-VLBA, DSS65, FORTLEZA, GILCREEK, HARTRAO, HATCREEK, HOBART26, KASHIM34, KAUAI, KOKEE, MATERA, MEDICINA, MOJAVE12, NRAO 140, NRAO85 3, ONSALA60, OV-VLBA, OVRO 130, RICHMOND USSURISK, VNDNBERG, WETTZELL.

The primary effect is a change in the station vertical position for az-el and x-y mount antennas and in the station north component for equatorial mount antennas.

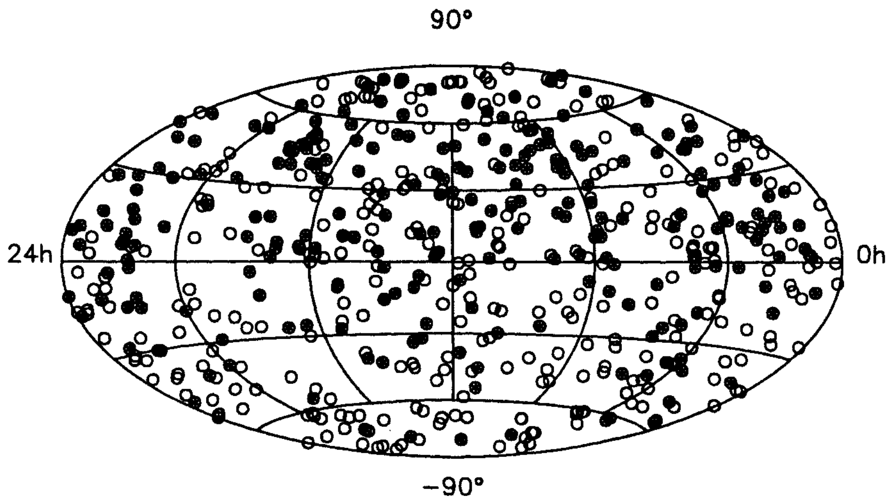
Observation weights are adjusted by session-dependent constants derived so that the chi-square per degree of freedom is unity in individual session solutions.

Data to SHANGHAI (7226), VLA (7619), USSURISK (7247) and DAITO (7326) lack ionosphere calibration.

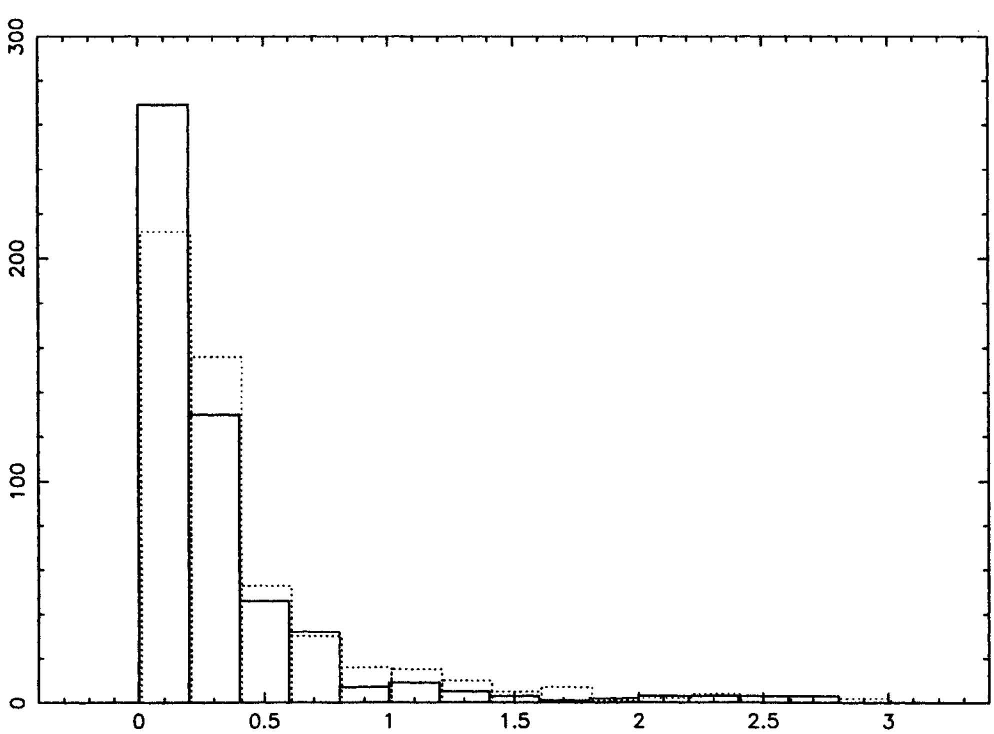
The solution in done is several steps to apply VLBI EOP information to some sessions.

Mean epochs are computed using the date of the session weighted by the number of good observations in the session for each source or site. The time span of observations is the difference between the date of the earliest session in which the given site or source appears and the date of the most recent session in which the same site or source appears. The central epoch and span for the sites (PRESIDIO, FORTORDS, SOURDOGH, YAKATAGA, WHTHORSE, MOJAVE12, DSS15, NRAO85 3) that appear more than once due to the application of a discontinuous motion model are calculated from the observations which were made in the sessions within the appropriate time interval.

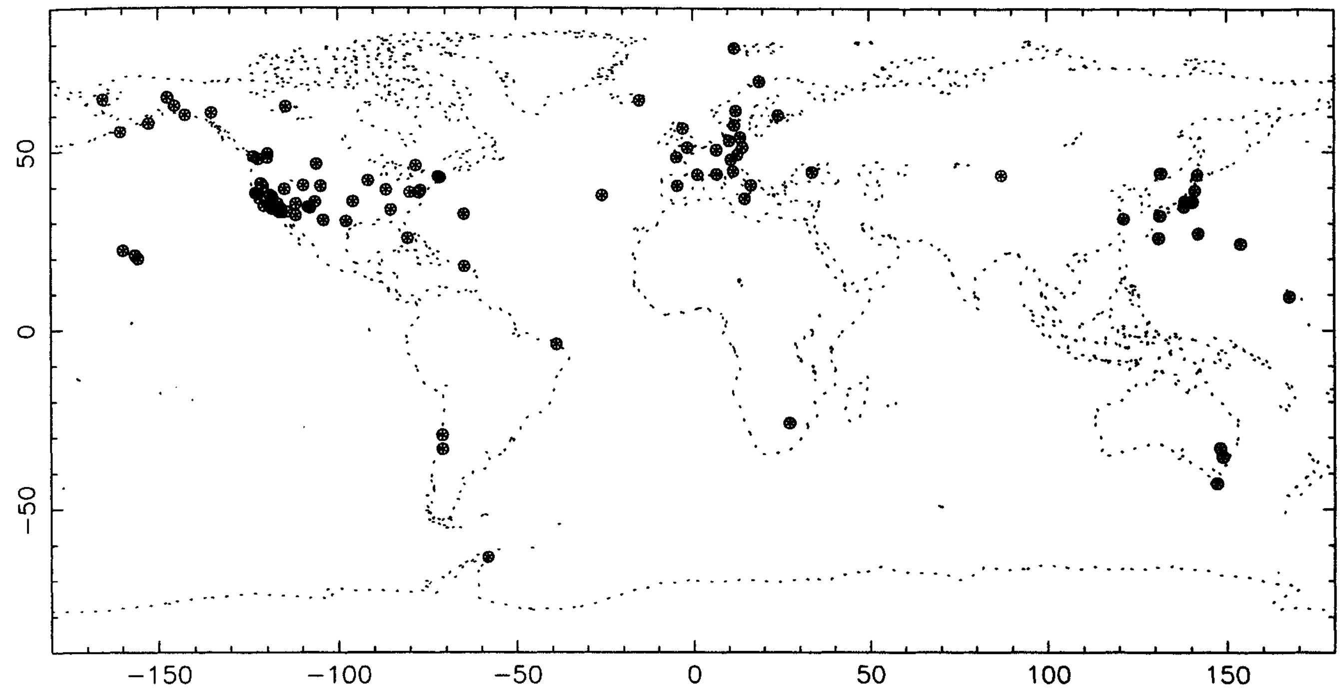
An entry for the EOP reference day 1993 September 30 is included in each EOP table although the values were, strictly speaking, not estimated. The purpose is to indicate the quality of the EOP determination for the reference day that sets the overall lower limit of the precision of the EOP series.



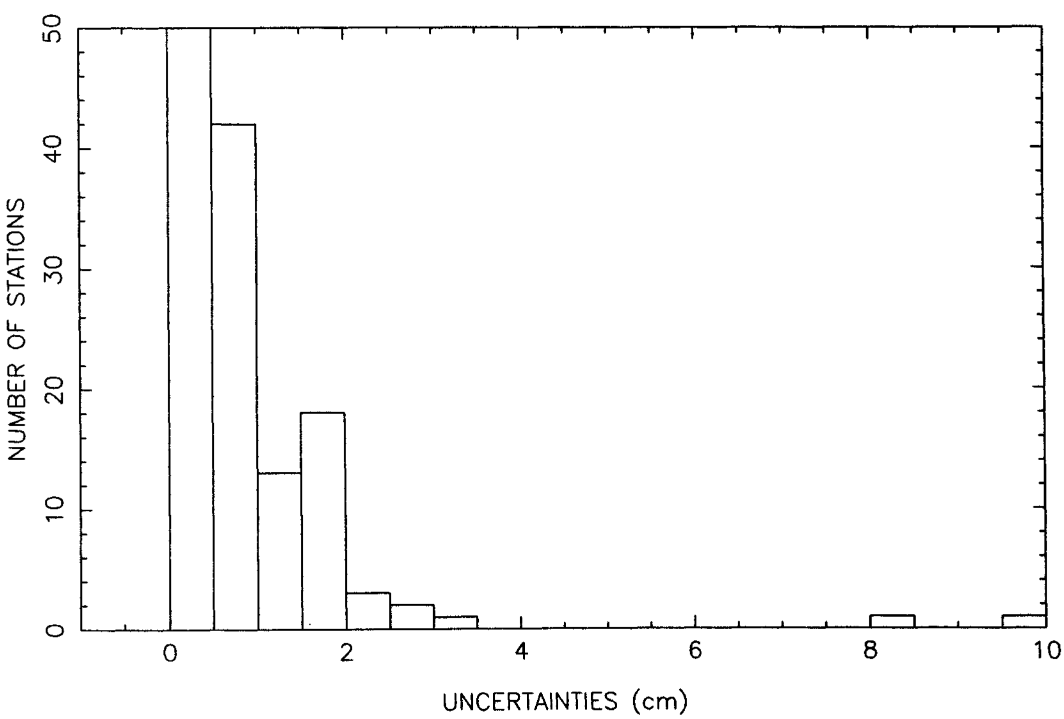
Distribution over the sky of the 550 extragalactic radio sources of the celestial frame RSC(GSFC) 95 R 01. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(GSFC) 95 R 01. 34 radio sources with uncertainties larger than 0.003" are not shown.



Distribution of the 104 sites of the terrestrial frame SSC(GSFC) 95 R 01.



Distribution of the uncertainties (quadratic mean of $\sigma_x, \sigma_y, \sigma_z$) for the 134 stations of the terrestrial frame SSC(GSFC) 95 R 01. 2 stations with uncertainties larger than 10 cm are not shown.

EOP(GSFC) 95 R 01

From Aug 1979 to Dec 1994

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

YEAR	X		Y		UT1		$\delta\psi$		$\delta\epsilon$	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
1979	2	1.17	2	2.28	2	0.85	2	1.86	2	0.66
1980	20	0.60	20	0.60	20	0.30	20	0.98	20	0.43
1981	34	13.06	34	41.06	34	10.57	34	3.21	34	1.14
1982	62	12.87	62	40.62	62	10.44	62	2.91	62	1.11
1983	85	12.66	85	33.25	85	10.22	85	2.27	85	0.93
1984	119	0.76	119	0.68	119	0.37	119	1.10	119	0.43
1985	131	0.47	131	0.45	131	0.24	131	0.73	131	0.28
1986	152	0.47	152	0.41	152	0.24	152	0.72	152	0.26
1987	185	0.46	185	0.43	185	0.24	185	0.71	185	0.26
1988	210	0.46	210	0.46	210	0.26	210	0.64	210	0.25
1989	247	0.34	247	0.35	247	0.19	247	0.55	247	0.22
1990	271	0.26	271	0.27	271	0.14	269	0.43	269	0.18
1991	248	0.21	248	0.22	248	0.12	244	0.38	247	0.16
1992	259	0.20	259	0.20	259	0.09	258	0.35	258	0.15
1993	194	0.16	194	0.14	194	0.07	193	0.26	193	0.11
1994	196	0.13	196	0.10	196	0.06	196	0.21	196	0.09

EOP(GSFC) 95 R 02
From Apr 1984 to Dec 1994

Number of measurements per year and median uncertainties
Units : 0.0001" for UT1

YEAR	UT1	
	Nb	Sigma
1984	64	1.16
1985	159	0.90
1986	234	0.84
1987	248	0.81
1988	255	0.63
1989	234	0.75
1990	261	0.64
1991	247	0.69
1992	191	0.39
1993	260	0.36
1994	203	0.34

EOP(GSFC) 95 R 03
From Apr 1989 to Apr 1993

Number of measurements per year and median uncertainties
Units : 0.0001" for UT1

YEAR	UT1	
	Nb	Sigma
1989	9	0.48
1990	54	0.90
1991	29	0.89
1992	20	0.50
1993	7	0.53

EARTH ROTATION PARAMETERS FROM DSN VLBI: 1995 JPL 95 R 01

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A description of the DSN VLBI data set and of last year's analysis can be found in last year's report (see IERS Technical Note 17, pp. R-19 to R-32). Other than including another year's data, the main changes in this year's analysis from last year's are in the use of meteorological data for determining tropospheric parameters and in the weighting of the data to account for the uncertainty in the observables caused by tropospheric effects and source structure. A priori dry zenith tropospheric delays were determined from barometric pressure measurements at the DSN sites, corrected for height differences between the pressure sensor and the antennas. A priori wet zenith tropospheric delays were derived from tables of monthly average wet zenith delays for each station, which are based on historical radiosonde data. The Lanyi function was used for mapping zenith tropospheric delays to observed elevations. The temperature at the top of the boundary layer, a parameter in the Lanyi function, was taken to be the 24-hour average of the surface temperature at the station. Adjustments to the wet troposphere zenith delays were estimated every two to three hours.

The raw observable uncertainties have been modified by adding quadratically four additional uncertainty components. The first component is a source-specific constant determined from source-specific residual scatter. It varies from 0 to 150 ps for delays (0 to 100 fs/s for delay rates), and tends to be associated with sources having known structure. The second and third components - one for each of the two stations - are proportional to the a priori wet tropospheric delay (which grows as elevation angle decreases) with a proportionality constant of 0.042 for delays and 7.5 10^{-5} sec^{-1} for delay rates. The fourth component is an "additive noise" constant selected to make the Chi Square of the postfit residuals approximately equal to the number of degrees of freedom in the solution. The delay and delay rate additive noise constants were adjusted separately for each CAT M&E observing session. For the TEMPO data, the additive noises were adjusted for each of several blocks of observing sessions. The change in the tropospheric error model compared to last year has dramatically reduced the size of the "additive noise" constants needed for the delay rate data.

During calendar year 1994, the TEMPO project produced earth rotation measurements from 91 dual frequency observing sessions, with a median standard error along the minor axis of the error ellipse of 0.3 milliarcseconds (mas), and along the major axis of 1.4 mas. During 1994 the median turnaround time for TEMPO measurements, from observation to availability of earth orientation parameters, was 48 hours.

In the Tidal ERP table below, the argument conventions are those of Sovers *et al.* (1993). The formal errors range from 11 to 46 microarcseconds but realistic uncertainties are probably about 70 microarcseconds (one standard deviation).

Acknowledgements. We would like to thank each and every one of the many people who contributed to the acquisition and analysis of the DSN VLBI data. The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Short Period Tidal ERP Variations

Term	Period (hours)	UT1 (microseconds) Cosine	UT1 (microseconds) Sine	Polar Motion Amplitude (microarcseconds) prograde	Polar Motion Amplitude (microarcseconds) retrograde	Polar Motion Phase (degrees) prograde	Polar Motion Phase (degrees) retrograde
K2	11.96724	1.6	2.7	46	58	45	229
S2	12.00000	0.1	9.3	5	130	53	310
M2	12.42060	-10.8	17.0	72	248	117	275
N2	12.65835	- 1.0	2.8	16	34	88	221
K1	23.93447	11.8	24.4	176	0	154	*
P1	24.06589	- 1.3	- 3.1	91	0	309	*
O1	25.81934	-10.6	-13.2	155	0	301	*
Q1	26.86836	3.2	- 2.0	42	0	326	*

Celestial Ephemeris Pole Motion Model (nutations relative to ZMOA-1990-2)

IAU-Index	Period days	Phase	Component	Adjustment mas	Formal Error mas	Generalized Error mas
precession			Longitude	-3.05/yr	0.05/yr	0.07/yr
obliquity rate			Obliquity	-0.26/yr	0.03/yr	0.03/yr
Y-offset			L sin eps	-17.59	0.23	0.36
X-offset			Obliquity	+ 5.61	0.36	0.37
1	-6798.38	In	Longitude	- 0.27	0.25	0.41
			Obliquity	- 0.06	0.08	0.08
		Out	Longitude	+ 0.30	0.16	0.21
			Obliquity	- 0.04	0.15	0.16
2	-3399.19	In	Obliquity	- 0.23	0.04	0.04
		Out	Longitude	- 0.29	0.10	0.11
			Obliquity	+ 0.09	0.08	0.08
10	365.26	In	Longitude	- 0.35	0.06	0.06
			Obliquity	+ 0.06	0.02	0.03
		Out	Longitude	+ 0.33	0.06	0.07
			Obliquity	- 0.01	0.02	0.03
9	182.62	In	Longitude	- 0.07	0.05	0.05
			Obliquity	- 0.02	0.02	0.03
		Out	Longitude	+ 0.17	0.06	0.06
			Obliquity	+ 0.03	0.02	0.02
31	13.66	In	Longitude	- 0.24	0.04	0.11
			Obliquity	+ 0.14	0.02	0.04
		Out	Longitude	+ 0.31	0.06	0.10
			Obliquity	+ 0.10	0.02	0.04
	-429.8	In	Longitude	- 0.24	0.06	0.07
			Obliquity	+ 0.03	0.02	0.03
		Out	Longitude	- 0.45	0.06	0.06
			Obliquity	- 0.15	0.03	0.03

Technical description of solution JPL 95 R 01

1 - Technique:	VLBI
2 - Analysis Center:	JPL
3 - Software used:	MODEST
4 - Data span:	Oct 78 - Jan 95
5 - Celestial Reference Frame:	RSC(JPL) 95 R 01
a - Nature:	extragalactic
b - Definition of the orientation:	The Right Ascension and Declination of OJ 287 (0851+202) and the Declination of CTD 20 (0234+285) were held fixed at the values specified in RSC(IERS) 94 C 01.
6 - Terrestrial Reference Frame:	SSC(JPL) 95 R 01
a - Relativity scale:	LE (TDT = geocentric with IAT) The relativity model used is essentially equivalent to the "consensus model" described by Eubanks.
b - Velocity of light:	299 792 458 m/s
c - Geogravitational constant:	3.9860 0448 10^{14} m^3 s^{-2}
d - Permanent tidal correction:	Yes
e - Definition of the origin, and f - Definition of the orientation:	Six constraints were applied to the nine coordinates (at epoch 1993.0) of DSS 15, DSS 45, and DSS 65, such that if a seven parameter transformation (3 translations, 3 rotations, 1 scale) between the JPL 1995-1 and ITRF-93 systems was estimated by unweighted least squares applied to the coordinates of DSS 15, 45, and 65, then the resulting 3 translation and 3 rotation parts of the transformation would be zero while the scale could be nonzero and unknown in advance of computing the catalog. (When expressed as the dot product of a nine dimensional unit vector with the nine station coordinates, each constraint is assigned an a priori standard deviation of 5 mm; this does not affect the resulting coordinates but does affect the calculated formal errors, giving them a more spherical distribution than would result if either very large or very small a priori standard deviations were used.)
g - Reference epoch:	1993.0
h - Tectonic plate model:	ITRF-93 plus adjustments
i - Constraint for time evolution:	Three-dimensional site velocities were estimated for each of the three DSN complexes. All stations in each DSN complex were assumed to have the same site velocity. The velocities were constrained so as to produce no net translation rate and no net rotation rate, for the network composed of the three DSN complexes, relative to the

net motion of this network of three sites as expressed in the ITRF-93 velocity field. (When expressed as the dot product of a nine dimensional unit vector with the nine site velocity components, each constraint is assigned an a priori standard deviation of 1.0 mm/yr; this does not affect the resulting velocity components but does affect the calculated formal errors, giving them a more spherical distribution than would result if either very large or very small a priori standard deviations were used.)

7 - Earth Orientation: EOP(JPL) 95 R 01

a - A priori nutation model: ZMOA-1990-2 plus adjustments

b - Short-period tidal variations in x, y, UT1:

As part of the JPL 1995-1 catalog solution we estimated coefficients of a model of ERP variations at nearly-diurnal and nearly-semidiurnal tidal frequencies. (Nearly-diurnal polar motion variations were constrained to have no retrograde part, thus allowing simultaneous estimation of nutations.) The reported earth rotation parameters have had these tidal frequency variations removed according to the parametric model estimated in the catalog solution. (In other words, these effects have NOT been added back in producing EOP(JPL) 95 R 01.)

8 - Estimated Parameters:

a - Celestial Frame: right ascension, declination (all sources, but see 5b)

b - Terrestrial Frame: X0, Y0, Z0 (by station), $\dot{X}, \dot{Y}, \dot{Z}$ (by site)

c - Earth Orientation: UT0-UTC and Variation of Latitude of the baseline vector

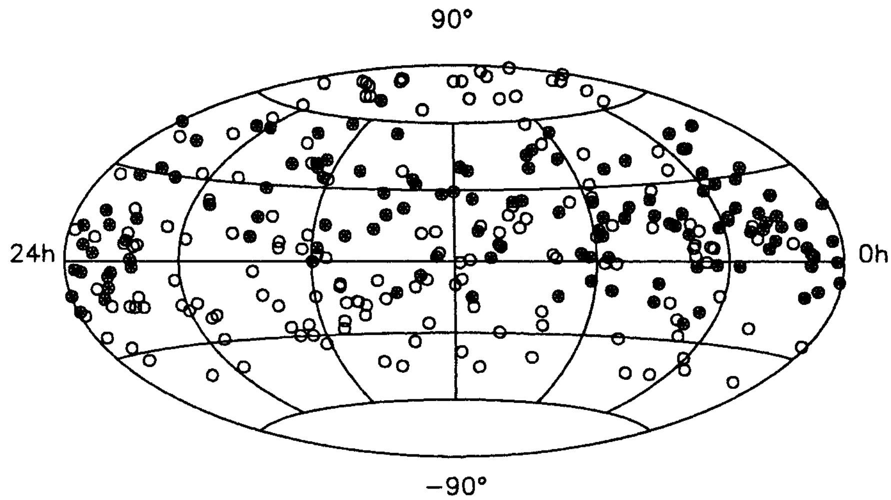
precession constant, obliquity rate, celestial pole offsets at J2000

coefficients of 23 nutation terms

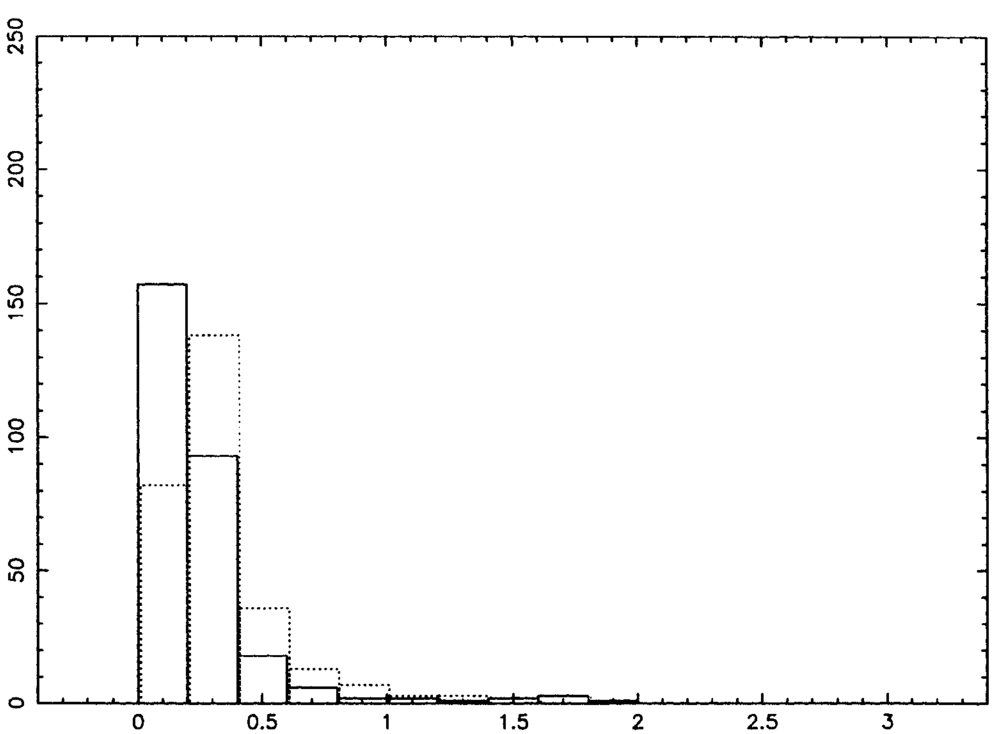
coefficients of 40 diurnal and semidiurnal tidal terms in ERP

d - Others: wet zenith tropospheric delays

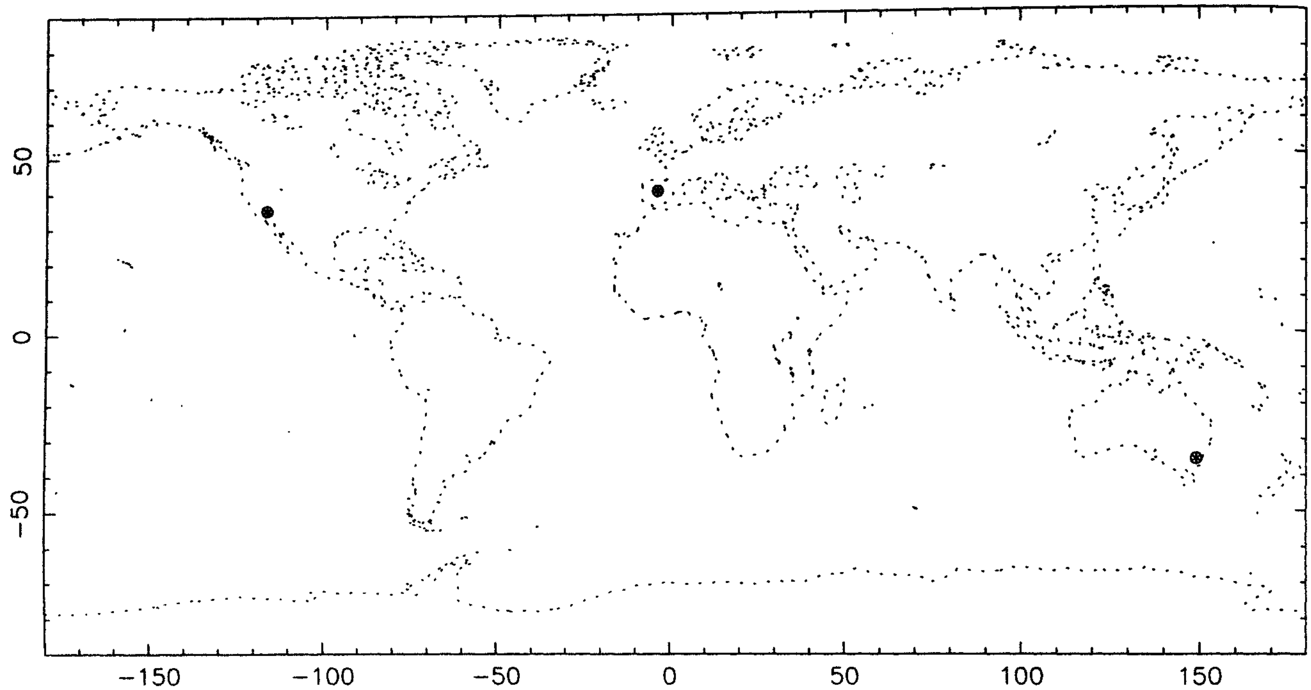
station clock offsets, rates, and frequency offsets



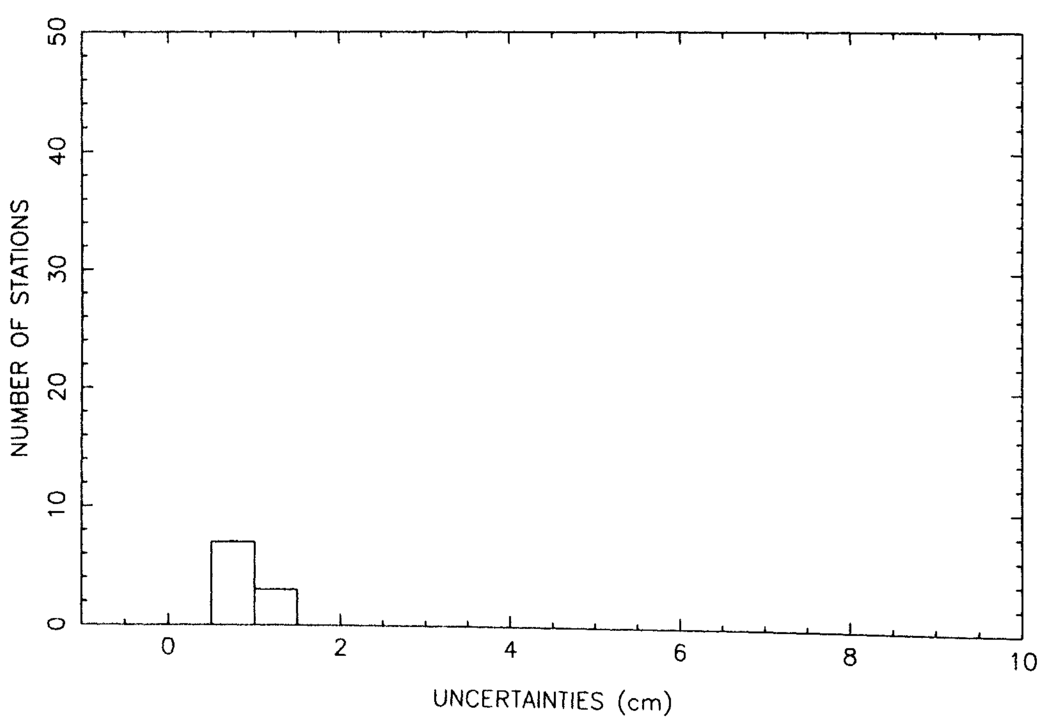
Distribution over the sky of the 287 extragalactic radio sources of the celestial frame RSC(JPL) 95 R 01. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(JPL) 95 R 01. 2 radio sources with uncertainties larger than 0.003" are not shown.



Distribution of the 3 sites of the terrestrial frame SSC(JPL) 95 R 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 10 stations of the terrestrial frame SSC(JPL) 95 R 01.

EOP(JPL) 95 R 01 From Oct 1978 to Jul 1995

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

YEAR	φ		UT0	
	Nb	Sigma	Nb	Sigma
1978	3	0.42	3	1.15
1979	6	1.84	6	1.83
1980	21	4.11	21	6.47
1981	17	2.81	17	5.75
1982	43	3.44	43	4.08
1983	74	3.03	74	4.91
1984	71	3.62	71	5.47
1985	19	2.18	19	3.78
1986	71	2.50	71	3.48
1987	77	2.08	77	3.43
1988	93	1.61	93	2.27
1989	89	0.78	89	1.70
1990	108	0.88	108	1.98
1991	111	0.45	111	1.06
1992	115	0.41	115	0.80
1993	101	0.59	101	0.89
1994	99	0.72	99	0.88
1995	42	0.90	42	0.85

RADIO SOURCE COORDINATES FROM DSN VLBI JPL 95 R 02

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California Institute of Technology; Pasadena, California 91109, USA

VLBI data collected from radio telescopes at the three NASA Deep Space Network sites (Australia, Spain, and the USA) by JPL between 1978 and 1994 were analyzed to yield a celestial reference frame. This celestial frame differs from RSC(JPL) 95 R 01 in three important respects: 1) no TEMPO data are included, 2) daily nutation corrections are estimated, rather than ZMOA-2 amplitudes, and 3) short-period UTPM corrections are modeled, not estimated. It contains coordinates of 290 radio sources and is tied to RSC(IERS) 94 C 01 through the right ascension of a single source, 0235+164. Daily nutation angle offsets were estimated from those given by the ZMOA-2 series, with 1992 March 22 serving as the reference day. The terrestrial frame is tied to ITRF-93 through the locations of the stations at the Goldstone site. A new set of coordinates is estimated for each experiment for stations at the other two sites. The time series SPACE94 [EOP(JPL) 95 C 01] is used to fix the UTPM part of Earth orientation. Nearly-diurnal and nearly-semidiurnal tidal frequency variations of UTPM were modeled with the parameters derived by Sovers, Jacobs and Gross (1993). Other aspects of modeling that departed from convention were the inclusion of the octupole components and frequency dependent Love numbers for the solid Earth tides, and a simple model for antenna thermal expansion.

The data base contains approximately 9000 Mark II (1978-89) and 14000 Mark III (1988-94) observations. Different tropospheric modeling was performed for these two classes. In both cases, a priori dry zenith tropospheric delays were determined from barometric pressure measurements at the DSN sites, corrected for height differences between the pressure sensors and the antennas. A priori wet zenith tropospheric delays were derived from tables of monthly average wet zenith delays for each station, which are based on historical radiosonde data. The Lanyi function was used for mapping zenith tropospheric delays to observed elevations. Three parameters in the Lanyi function were assigned values that differ from the defaults. The temperature at the top of the boundary layer was taken to be the 24-hour average of the surface temperature at the station. Both the tropopause height and temperature lapse rate were taken to be the monthly average values derived from radiosonde data at Australia and Spain, while global averages were used for Goldstone. Adjustments to the wet troposphere zenith delays were estimated every two to three hours for the Mark II experiments, and every 12 hours for Mark III. An a priori covariance matrix was introduced for each Mark III experiment. It is based on the turbulent troposphere model of Treuhaft and Lanyi (1987), with two empirically adjusted parameters at each station: wind direction and fluctuation scale. No external elevation cuts were applied: the elevation limits were imposed by the antenna and horizon geometry (6 degrees).

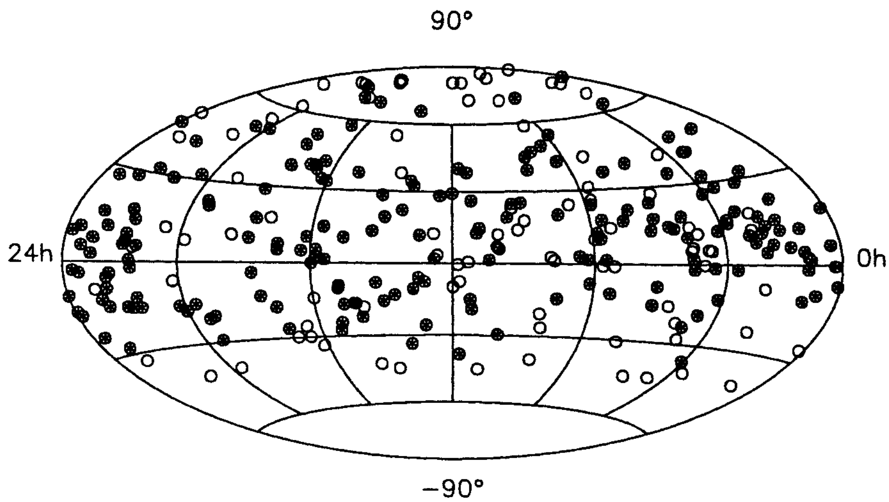
The raw observable uncertainties were further modified by quadratic addition of four additional uncertainty components. Only the first of these was used for Mark III data: a source-specific constant determined from source-specific residual scatter, which varies from 0 to 150 ps for delays (0 to 100 fs/s for delay rates), and which tends to be associated with sources having known structure. Such downweighting was applied to a total of 39 sources. Mark II data weights also included troposphere errors modeled as components proportional to the a priori wet troposphere contribution to each observable (which grow as the elevation angle decreases) at each of the two stations, with proportionality constants of

0.042 for delays and 0.24 for delay rates. The fourth component is an "additive noise" constant selected to make the normalized chi square of the postfit residuals approximately 1. These delay and delay rate additive noise constants were adjusted separately for each observing session.

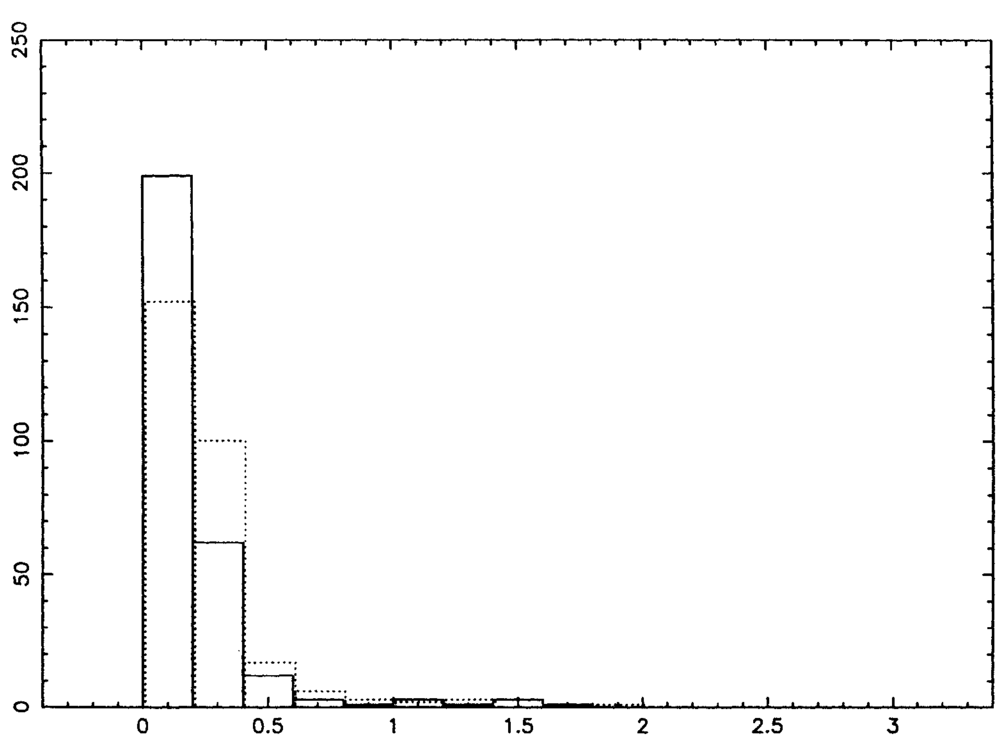
There is a minimum of 10 observations for all but 9 of the 290 sources, ranging up to a maximum of 403 for 1641+399. All but 12 sources have declination uncertainties below 1 mas, with the median being 0.21 mas. In spite of the special care employed to ensure realistic error assignment based on source structure and troposphere considerations, the declination uncertainties are as small as 80 microarcseconds for a number of sources at high declinations. Based on external catalog comparisons, we consider these formal uncertainties to be overly optimistic.

Technical description of solution JPL 95 R 02

1 - Technique:	VLBI
2 - Analysis Center:	JPL
3 - Software used:	MODEST
4 - Data span:	Oct 78 - Nov 94
5 - Celestial Reference Frame:	RSC(JPL) 95 R 02
a - Nature:	Extragalactic
b - Definition of the orientation:	The right ascension and declination of 0235+164 was held fixed at the value specified in RSC(IERS) 94 C 01.
6 - Terrestrial Reference Frame:	SSC(JPL) 95 R 02
a - Relativity scale:	LE (TDT = geocentric with IAT)
b - Velocity of light:	299 792 458 m/s
c - Geogravitational constant:	3.9860 0448 10^{14} m^3s^{-2}
d - Permanent tidal correction:	Yes
e - Definition of the origin:	Goldstone stations fixed
f - Definition of the orientation:	UTPM values fixed at EOP(JPL) 95 C 01
g - Reference epoch:	None (daily adjustments)
h - Tectonic plate model:	None (daily adjustments)
i - Constraint for time evolution:	None
7 - Earth Orientation:	EOP(JPL) 95 C 01
a - A priori nutation model:	ZMOA-1990-2
b - Short-period tidal variations in x, y, UT1:	Model and coefficients of Sovers, Jacobs, Gross, JGR 98, 19959 (1993)
8 - Estimated Parameters	
a - Celestial Frame:	Right ascension, declination (all sources, but see 5b)
b - Terrestrial Frame:	Daily X, Y, Z for Spain and Australia stations
c - Earth Orientation:	Daily celestial pole offsets, with 92/3/22 reference day
d - Others:	Dry zenith tropospheric delays Wet zenith tropospheric delays Station clock offsets, rates, and frequency offsets



Distribution over the sky of the 290 extragalactic radio sources of the celestial frame RSC(JPL) 95 R 02. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(JPL) 95 R 02. 5 radio sources with uncertainties larger than 0.003" are not shown.

NOAA EARTH ORIENTATION AND REFERENCE FRAME RESULTS DERIVED FROM VLBI OBSERVATIONS: FINAL REPORT

NOAA 95 R 01, 02

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Results from two VLBI solutions are submitted using nearly 207000 more observations this year, an increase of more than 20% over last year. Most of the available Mark III VLBI data from 1980 September through 1994 have been included. NOAA 95 R 01 reports estimated values for the coordinates of 249 radio sources (73 more than last year), terrestrial site coordinates and velocities for 111 points (5 more than last year), and a time series of 1773 Earth orientation values. A separate series of quasi-daily UT1 values is reported in NOAA 95 R 02 for 2397 epochs, referenced to the NOAA 94 R 01 system. All tidal effects are included in the reported EOP values, including diurnal and semi-diurnal variations.

The most significant changes since our submission last year [Ray *et al.*, 1994] are summarized below:

• First data are included from the following VLBI facilities: 25-m OV-VLBA antenna (Owens Valley, CA, USA), 22-m CRIMEA antenna (Simeiz, Crimea), 25-m URUMQI antenna (China), and 20-m NYALES20 antenna (Ny Alesund, Spitzbergen). The time series of data from DSS15 (Goldstone, CA, USA) was broken into two segments, before (DSS15) and after (DSS15pq) the Landers earthquake of 1992 June 28; the velocity of each segment was constrained to agree with that of MOJAVE12.

• During 1994, several significant changes were made in the VLBI observing procedures for the quasi-daily UT1 observing sessions. At the start of the year, the frequency sequences were changed to the same set of wideband sequences used in the NEOS-A sessions. On 1994 Feb. 24, WESTFORD was replaced by NRAO85_3 as the western end of the VLBI baseline. Beginning 1994 Jul. 01, the data acquisition mode was changed from 14 channels using upper sideband only with 4-MHz bandwidth sampled in each channel to 28 channels using upper and lower sidebands with 2-MHz bandwidth sampled in each channel. Both modes record the same number of data samples and therefore yield the same sensitivity.

Our data analysis procedures are otherwise the same as those described last year [Ray *et al.*, 1994].

References

Ray, J.R., Abell, M.D., Carter, W.E., Dillinger, W.H., Morrison, M.L., and Robertson, D.S., 1994: NOAA Earth Orientation and Reference Frame Results Derived from VLBI Observations: 1994 Analysis Procedures, in *IERS Technical Note 17* (P. Charlot, ed.), Observatoire de Paris, Paris, p. R-37 - R-62.

Technical description of solutions NOAA 95 R 01 and 95 R 02

1 - Technique: VLBI

2 - Analysis Center: NOAA VLBI Analysis Center, Geosciences Laboratory, N/OES13, SSMC-4, 1305 East-West Highway, Silver Spring, MD, USA 20910-3281

3 - Software used: COREL and FRNGE for the Mark III data correlation and fringe-fitting; DE200 ephemerides; CALC-7.6 for theoreticals and partials; SOLVE-3 for parameter estimation.

4 - Data span: Sep. 1980 - Jan. 1995 for NOAA 95 R 01
Apr. 1984 - Dec. 1994 for NOAA 95 R 02

5 - Celestial Reference Frame: RSC(NOAA) 95 R 01
- a - Nature: Extragalactic radio sources
- b - Definition of the orientation: The RA origin at epoch J2000.0 is specified by constraining the sum of the adjusted RA values for 71 "primary" sources (each weighted by the cosine of its declination) to equal the corresponding sum obtained from RSC(IERS) 93 C 01.
The orientation is specified by fixing the EOP values for the reference epoch 1991 August 12 19:49:50 at values interpolated from the EOP(IERS) 90 C 04 series.

6 - Terrestrial Reference Frame: SSC(NOAA) 95 R 01
- a - Relativity scale: Radio source coordinates are in SSB system; terrestrial site coordinates are geocentric (ignoring the local gravitational potential of the Earth)
- b - Velocity of light: 299 792 458. m/s
- c - Geogravitational constant: not applicable
- d - Permanent tidal correction: No correction is applied to remove the zero-frequency displacement introduced by the solid Earth tide model.
- e - Definition of origin:
The coordinate origin of the terrestrial reference frame is specified by setting the vector sum of the adjusted coordinates for 20 VLBI sites equal to the corresponding vector sum for ITRF-92 at epoch 1988.0. The sites used in the origin constraint are:

WESTFORD, RICHMOND, ALGOPARK, GILCREEK, NRAO85_3, PLATTVIL, MOJAVE12, OVRO_130, VNDNBERG, ONSALA60, EFLSBERG, WETTZELL, KASHIMA, SESHAN25, DSS65, KAUAI, KWAJAL26, HOBART26, DSS45, and HARTRAO.

- f - Definition of orientation: The orientation is specified by fixing the EOP values for the reference epoch 1991 August 12 19:49:50 at values interpolated from the EOP(IERS) 90 C 04 series.
- g - Reference epoch: 1993.0
- h - Tectonic plate model: NNR-NUVEL1A
- i - Constraint for time evolution:
The secular translational velocity and rotational velocity of the terrestrial reference frame are specified through a set of constraints to match the net motion of the NNR-NUVEL1A model for 10 VLBI sites. The sites used in the velocity constraints are:

WESTFORD, RICHMOND, ALGOPARK, GILCREEK, NRAO85_3, PLATTVIL, ONSALA60, EFLSBERG, WETTZELL, and KAUAI.

7 - Earth orientation: EOP(NOAA) 95 R 01, R 02

a - A priori nutation model: The IAU(1980) nutation model is applied a priori and the reported nutation offset values are with respect to this model. However, the ZMAO-1990.2 model is also used to model the time variation between tabular points in the NOAA EOP a priori file.

b - Short-period tidal variations in x, y, UT1: The model of Herring [1993] has been used to model tidal variations in x, y, and UT1 near diurnal and semi-diurnal frequencies. These tidal effects are included in the reported EOP values.

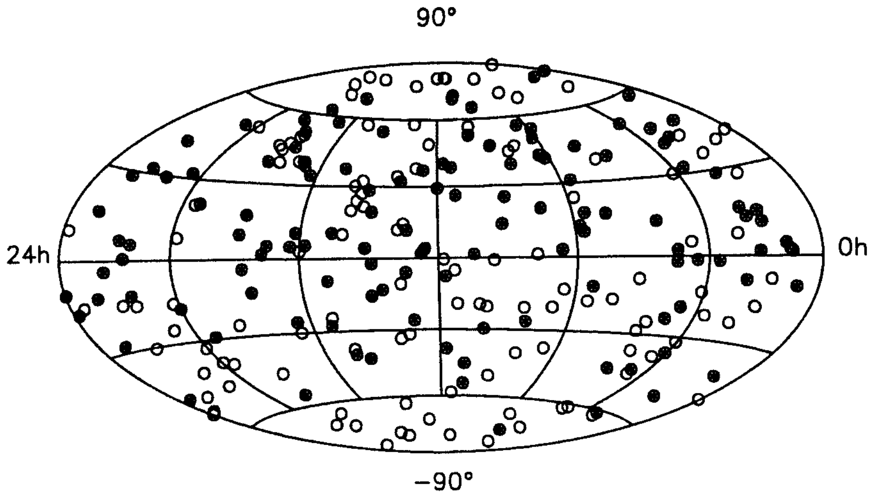
8 - Estimated Parameters:

a - Celestial Frame: Right ascension, declination.
A constraint is applied such that the sum of the adjusted RA values for 71 "primary" radio sources (each weighted by the cosine of its declination) equals the corresponding sum from RSC(IERS) 93 C 01.
No celestial frame parameters are adjusted for EOP(NOAA) 95 R 02.

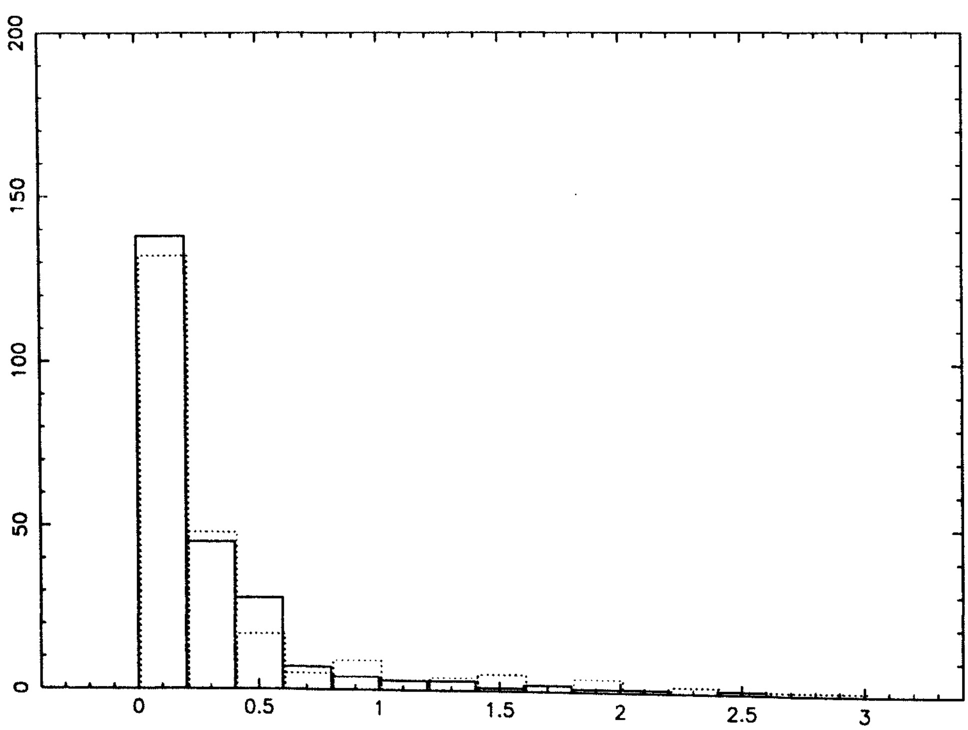
b - Terrestrial Frame: X0, Y0, Z0, Xdot, Ydot, Zdot.
Constraints are applied, as described above, to fix the coordinate origin and to fix the net translational and rotational velocities; note that the coordinates are estimated at the mean epoch for each site and subsequently projected to a common epoch.
No terrestrial frame parameters are adjusted for EOP(NOAA) 95 R 02.

c - Earth Orientation: x, y, UT1-UTC, $\delta\psi$ $\delta\epsilon$.
EOP values for the reference epoch 1991 August 12 19:49:50 are held fixed at values interpolated from the EOP(IERS) 90 C 04 series.
Only UT1-UTC parameters are adjusted for EOP(NOAA) 95 R 02.

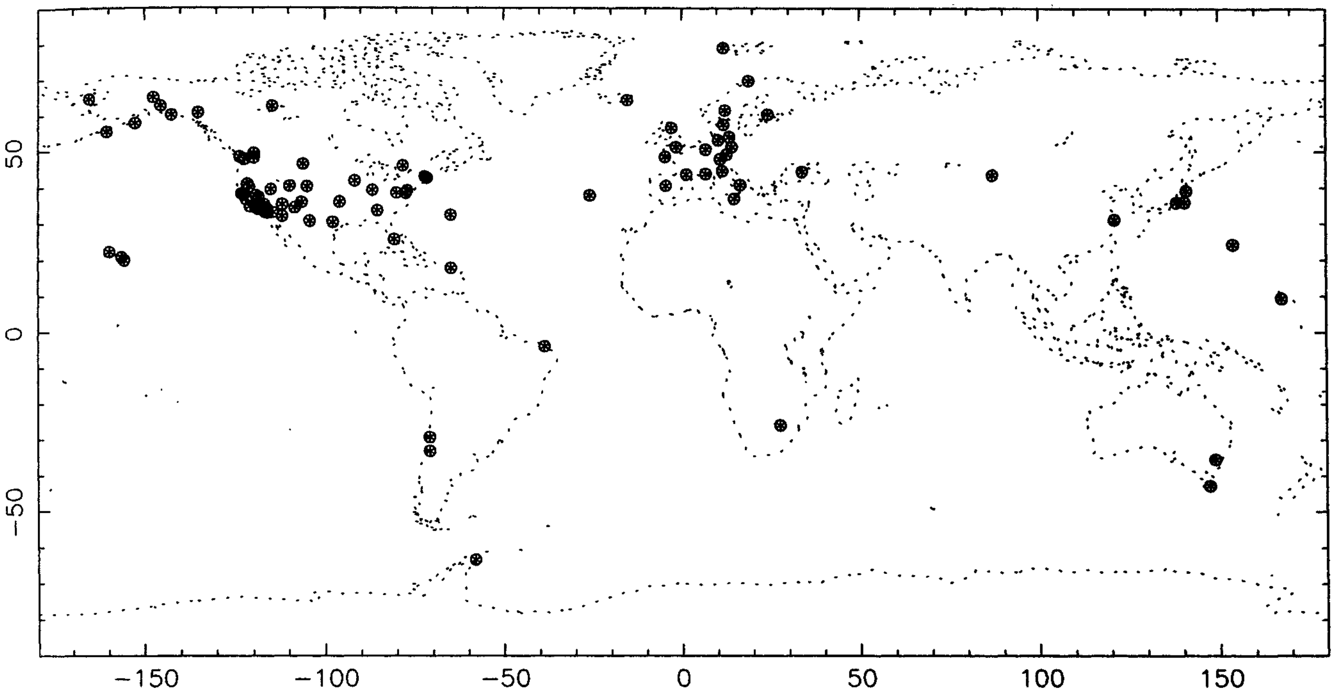
d - Others:
- residual zenith tropospheric delay at each VLBI site using constrained offset parameters at each 1-hour interval and the NMF "dry" and "wet" mapping models; no tropospheric parameters are adjusted for EOP(NOAA) 95 R 02.
- station clock offsets relative to one reference clock in each observing session using segmented polynomial models; only one clock offset and one clock rate parameter are adjusted for EOP(NOAA) 95 R 02.
- no observations with an elevation angle below 5 degrees are included in the analysis.



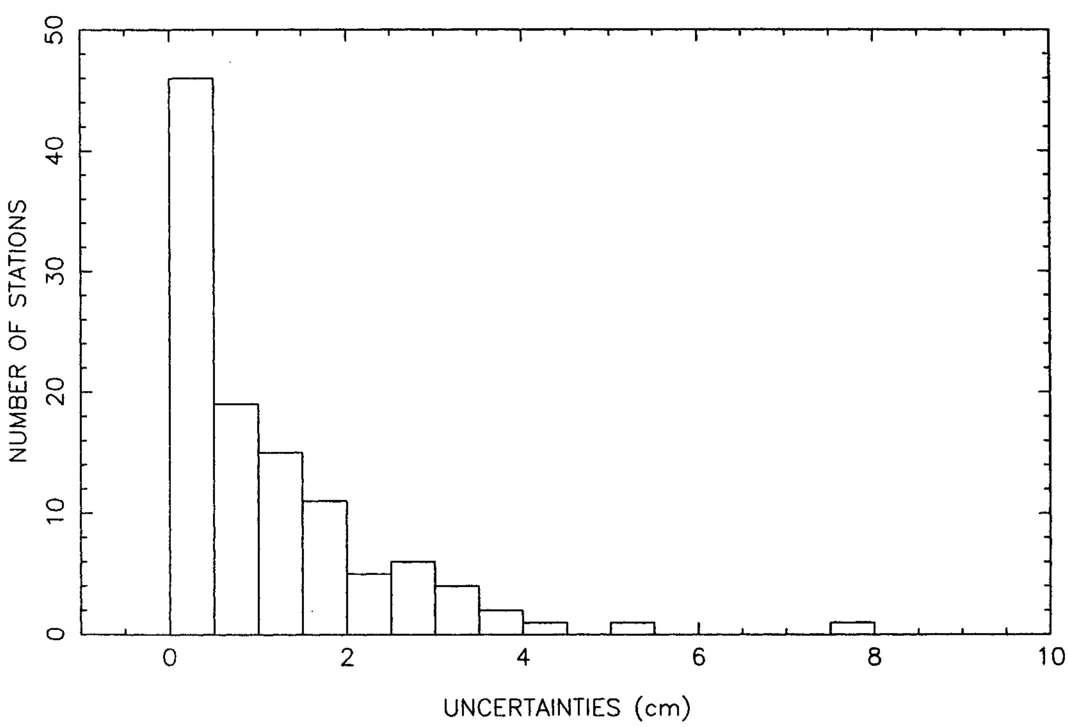
Distribution over the sky of the 249 extragalactic radio sources of the celestial frame RSC(NOAA) 95 R 01. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(NOAA) 95 R 01. 15 radio sources with uncertainties larger than 0.003" are not shown.



Distribution of the 94 sites of the terrestrial frame SSC(NOAA) 95 R 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 111 stations of the terrestrial frame SSC(NOAA) 95 R 01.

EOP(NOAA) 95 R 01

From Sep 1980 to Jan 1995

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

YEAR	X		Y		UT1		δψ		δε	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
1980	16	0.62	16	0.66	16	0.31	16	0.98	16	0.33
1981	6	0.99	6	1.14	6	0.57	6	1.33	6	0.46
1982	10	1.09	10	0.97	10	0.45	10	1.76	10	0.51
1983	17	0.96	17	1.74	17	0.72	17	1.58	17	0.49
1984	82	0.66	82	0.69	82	0.36	82	0.99	82	0.35
1985	108	0.43	108	0.44	108	0.22	108	0.62	108	0.23
1986	120	0.41	120	0.39	120	0.20	120	0.59	120	0.22
1987	141	0.43	141	0.42	141	0.20	141	0.61	141	0.23
1988	159	0.39	159	0.37	159	0.20	159	0.53	159	0.21
1989	186	0.33	186	0.32	186	0.16	186	0.46	186	0.19
1990	194	0.24	194	0.24	194	0.12	194	0.37	194	0.15
1991	173	0.20	173	0.21	173	0.09	173	0.33	173	0.13
1992	218	0.21	218	0.22	218	0.09	218	0.34	218	0.14
1993	169	0.16	169	0.15	169	0.07	169	0.28	169	0.12
1994	172	0.14	172	0.14	172	0.06	172	0.26	172	0.11
1995	1	0.12	1	0.13	1	0.05	1	0.23	1	0.09

EOP(NOAA) 95 R 02

From Apr 1984 to Dec 1994

Number of measurements per year and median uncertainties
Units : 0.0001s for UT1

YEAR	UT1	
	Nb	Sigma
1984	64	1.00
1985	159	0.57
1986	237	0.58
1987	245	0.56
1988	255	0.56
1989	234	0.58
1990	261	0.58
1991	247	0.55
1992	223	0.40
1993	260	0.39
1994	212	0.40

ANALYSIS OF THE IRIS VLBI INTENSIVE SESSIONS EOP(OPA) 95 R 01

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The series is based on the analysis of VLBI observations obtained in the frame work of the IRIS program on the Wettzell-Westford baseline over 1988-1994 and on the Wettzell-NRAO85-3 baseline since March 1994. The latitude of the stations are respectively 49°, 43° and 38° N. The observations consist of two scans of each of the four radio sources in the program (four scans since October 1991), repeated on all days when no 24h routine IRIS-A is scheduled. The observation list includes two high declination sources (0212+735, 1803+784), and two lower declination sources which are changed about every three months. This scheduling results in three-month batches with constant geometry and sidereal time of observation. It is optimised for the determination of universal time. The analysis is similar to that described by Gontier *et al.* (1993).

The data analysis includes the adoption of fixed values for the coordinates of stations and sources, for the pole coordinates (x, y) and the celestial pole offsets ($d\psi$, $d\varepsilon$). All values were adopted from homogeneous IERS results: SSC(IERS) 94 C 01 and the NNR-NUVEL1 model for the terrestrial frame, RSC(IERS) 94 C 01 for the celestial frame, and EOP(IERS) 90 C 04 for the terrestrial and celestial coordinates of the pole (corrected for the bias recommended in the 1993 IERS Annual Report, p. II-19).

Modelling of observations is made with the French-developped software GLORIA (Global Radio-Interferometry Analysis, see Gontier 1992), which follows generally the IERS Standards (McCarthy, 1992), with the following peculiarities:

- the transformation between the terrestrial frame and the celestial frame makes use of Guinot's (1979) non-rotating origin (or departure point) concept (Gontier 1991, Capitaine and Gontier 1993),

- the tropospheric correction is based on Saastamoinen (1972) zenith delay using the CFA 2.2 mapping function (Davis *et al*, 1985) for the dry component and the Chao (1974) mapping function for the wet component (see the references in the IERS Standards, McCarthy, 1992).

- the BDL2000 ephemeris (Chapront-Touzé and Chapront 1983, Bretagnon 1982).

Editing of observations is performed by using an L_1 norm analysis of each session to detect outliers. This estimation technique (minimizing the sum of absolute values of residuals) is known to be less sensitive to outliers than the least-squares (L_2 norm) technique when the degree of freedom of an estimation is low (Bougeard 1992).

Acknowledgements. We are thankful to J. Morrison (NOAA) for providing the past and current observation data sets, and to J. Souchay (Paris Observatory) for the L_1 norm estimation software.

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EOP(OPA) 95 R 01 From Jan 1988 to Dec 1994

Number of measurements per year
and median uncertainties
Units : 0.0001s for UT1

YEAR	UT1 Nb	UT1 Sigma
1985	157	0.34
1986	236	0.32
1987	245	0.30
1988	255	0.27
1989	233	0.29
1990	261	0.26
1991	239	0.22
1992	211	0.23
1993	255	0.17
1994	211	0.15

EARTH ROTATION AND REFERENCE FRAMES FROM VLBI ANALYSIS

SHA 95 R 01

Yang Zhigeng - Shanghai Observatory

The SHA Earth orientation reduction depends on the reference frames, which were derived from all available VLBI data of IRIS-A network in 1993 and NEOS-A network in 1994, instead of using both the celestial and terrestrial reference frames of a global VLBI solution of the VLBI group at NASA Goddard Space Flight Center. This is a considerable difference from previous solutions, which were only SOLVK EOP solution.

The SHA VLBI celestial and terrestrial reference frame were obtained from the available VLBI data mentioned above in a two solution process. In the first solution, the calculation was made by using SOLVK software, in which, the polar motion of EOP(NEOS) 94 R 01 series was treated as a priori pole position for each session and the priori UT1 measurement value for each session was also taken from the same series by first removing the IERS standard tidal model, interpolating with a spline to the epoch of session, and then restoring the standard tidal model. The nutation in longitude and obliquity was estimated at the same time in this first solution. The positions of radio sources and stations were fixed, in which the right ascensions and declinations of all observed sources and the coordinates of stations in IRIS-A and NEOS-A networks were respectively taken from the values of IERS combined celestial reference frame RSC(IERS) 94 C 01 and the terrestrial reference frame SSC(IERS) 94 C 01.

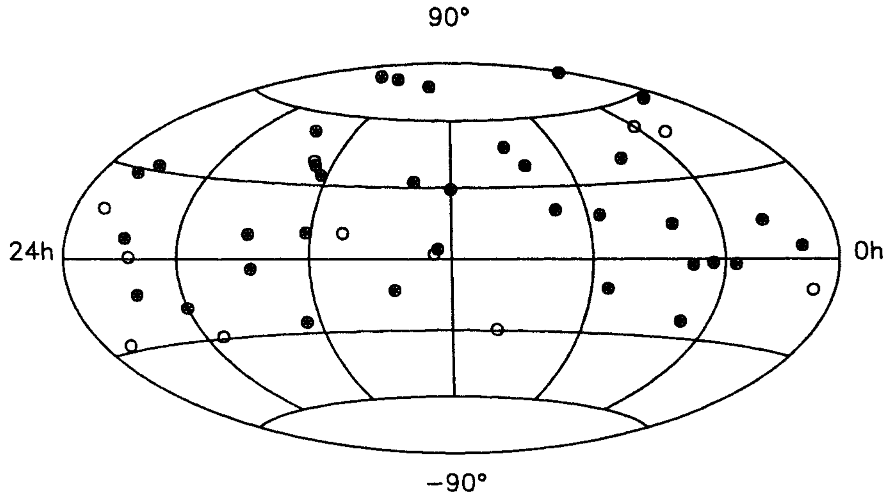
In the second solution, the right ascension of the source 0229+131 and the declination of two sources 0229 + 131 and 0851 + 202 were held fixed at the values given in RSC(IERS) 94 C 01. The position of Wettzell was fixed to define the origin of the terrestrial frame while its orientation was defined by fixing the direction from Westford to Wettzell. The updated ERP parameters in the first solution were treated as a priori measurements in this solution. Then, all parameters, including ERP and nutation offsets of each session,and the positions of the observed sources and involved stations, except for the reference radio sources and stations mentioned above, were globally adjusted. The second solution, as final results, was submitted to IERS.

The estimations of station positions were only calculated in the second solution, because it is difficult to estimate the station velocities by using only these two years data of VLBI experiments with the adequate accuracies. Therefore, the station velocities of NNR-NUVEL1 tectonic plate motion model were adopted for this solution.

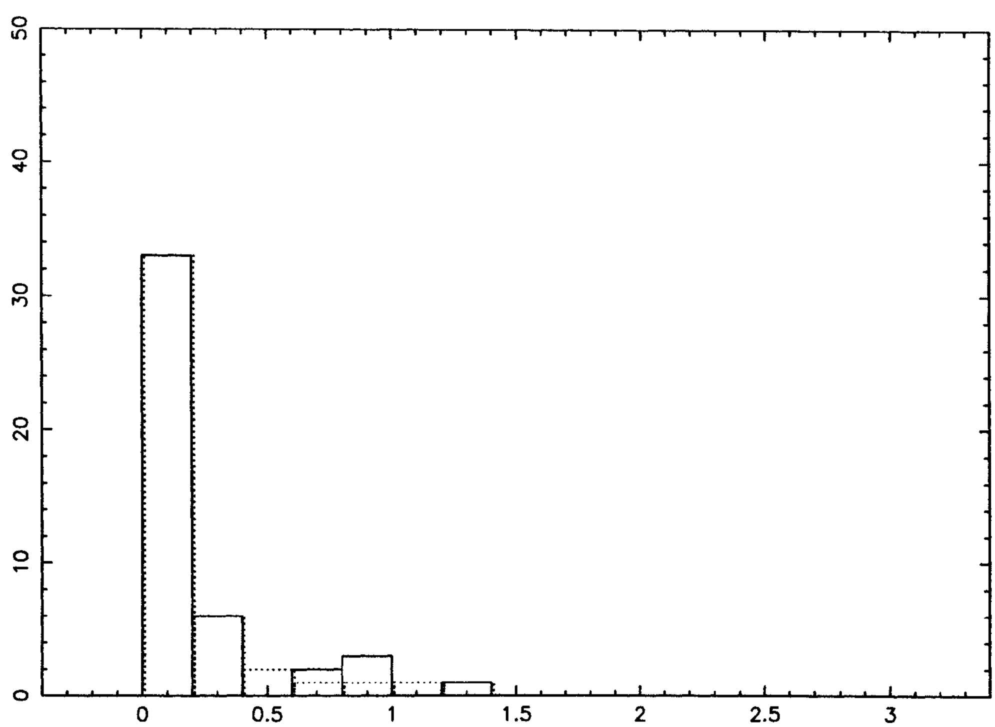
The data analysis in this report used the standard models which were adopted in CALC 7.6 software.

Technical description of solutions SHA 95 R 01

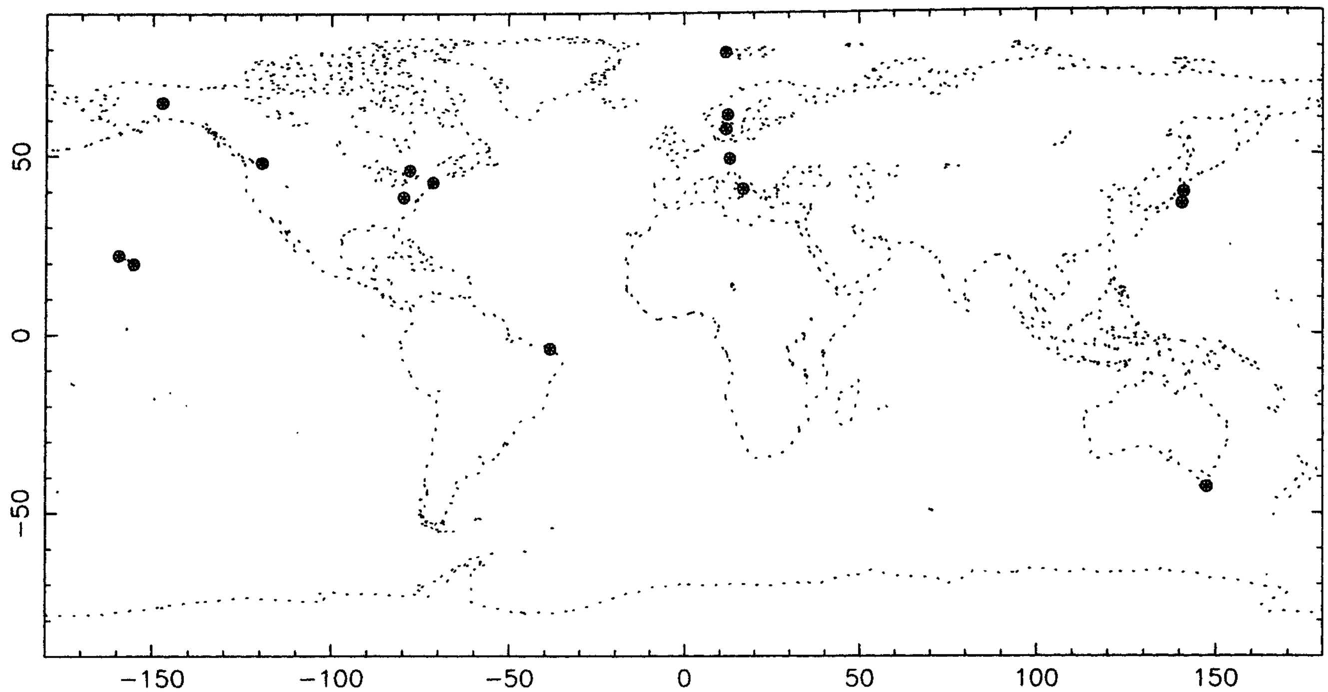
1 - Technique:	VLBI
2 - Analysis Center:	SHA
3 - Software used:	CALC7.6, SOLVK/GLOBK
4 - Data span:	Jan.1993 - Dec.1994
5 - Celestial Reference Frame:	RSC(SHA) 95 R 01
a - Nature:	Extragalactic radio sources
b - Definition of the orientation:	The orientation of the frame is defined by fixing the right ascension of 0229+131 and the declinations of 0229+131 and 0851+202
6 - Terrestrial Reference Frame:	SSC(SHA) 95 R 01
a - Relativity scale:	solar system barycentric (SSB)
b - Velocity of light:	299792458 m/s
c - Geogravitational constant:	3.986004415 10^{14} $m^3 s^{-2}$
d - Permanent tidal correction:	No
e - Definition of origin:	By fixing Wettzell coordinates (m) at 1993.0 (4075539.946, 931735.204, 4801629.319)
f - Definition of orientation:	By fixing the direction from Wettzell to Westford at the reference epoch
g - Reference epoch:	1993.0
h - Tectonic plate model:	NNR-NUVEL1
i - Constraint for time evolution:	Linear in time by fixing NNR-NUVEL1 plate motion model
7 - Earth orientation:	EOP(SHA) 95 R 01
a - A priori nutation model:	IAU(1980) nutation series
b - Short-period tidal variations in x,y,UT1:	No
8 - Estimated Parameters:	
a - Celestial frame:	right ascension, declination
b - Terrestrial frame:	X0, Y0, Z0
c - Earth orientation:	x, y, UT1-UTC, $\delta\psi$, $\delta\epsilon$
d - Others:	atmospheric zenith time delays, station clock offsets



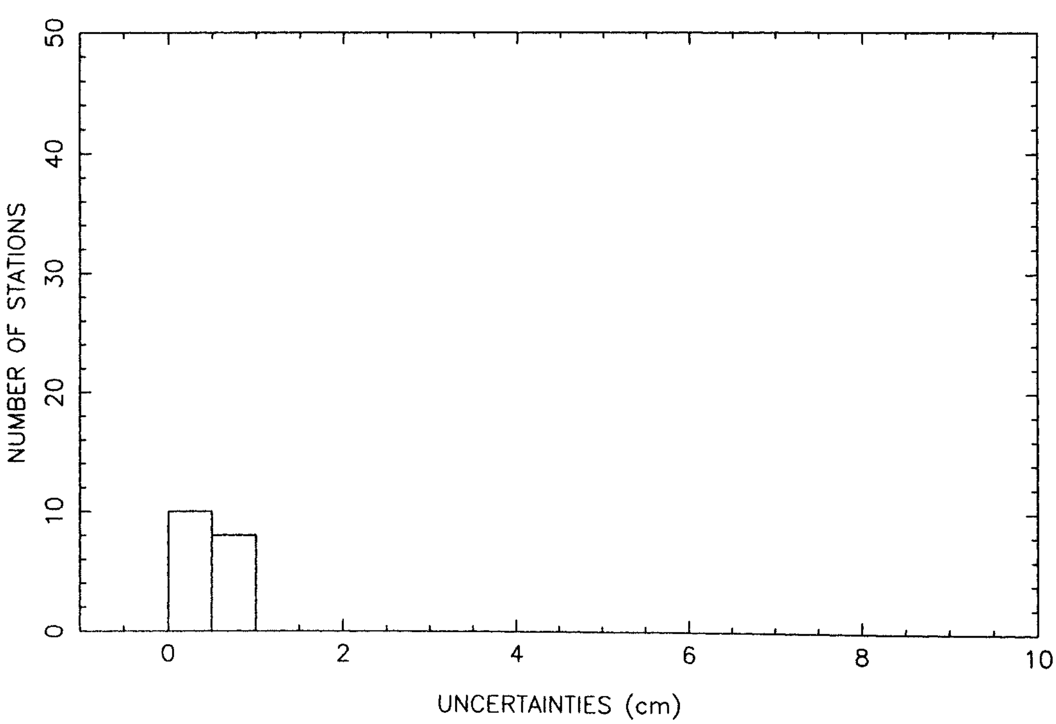
Distribution over the sky of the 45 extragalactic radio sources of the celestial frame RSC(SHA) 95 R 01. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(SHA) 95 R 01.



Distribution of the 16 sites of the terrestrial frame SSC(SHA) 95 R 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 18 stations of the terrestrial frame SSC(SHA) 95 R 01.

EOP(SHA) 95 R 01 From Jan 1993 to Dec 1994

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

YEAR	X		Y		UT1		$\delta\psi$		$\delta\varepsilon$	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
1993	65	0.16	65	0.12	65	0.07	65	0.30	65	0.12
1994	51	0.10	51	0.07	51	0.05	51	0.18	51	0.08

CELESTIAL FRAME: RORF94 RSC(USNO) 95 R 00

Reference: Johnston *et al.* (1995), submitted to AJ (copies available upon request)

A catalog is presented based on the radio positions of 436 extragalactic sources distributed over the entire sky. The positional accuracy of the sources is better than 3 mas in both coordinates, with the majority of the sources having errors better than 1 mas. This catalog is based upon a baseline solution (using CALC 7.6 and SOLVE 4.x) of all applicable dual frequency 2.3 GHz and 8.4 GHz Mark--III VLBI data available through the end of 1993 consisting of 1,015,292 pairs of group delay and phase delay rate observations. This includes the majority of the data collected between late 1979 and the end of 1993 by NASA, NOAA, JPL, USNO, and NRL. The final orientation of the catalog has been obtained by a rotation of the positions into the system of the International Earth Rotation Service (IERS) and is consistent with the FK5~J2000.0 optical system, within the limits of the link accuracy.

The positions of the sources were solved for as global parameters. All other parameters were arc parameters in the solution. The coordinates of each station were estimated as arc parameters with the exception that the position of one station in each experiment was fixed to its a priori value and served as the local zero point of the terrestrial frame. Thus no terrestrial frame or model assumptions for long term station motions were used.

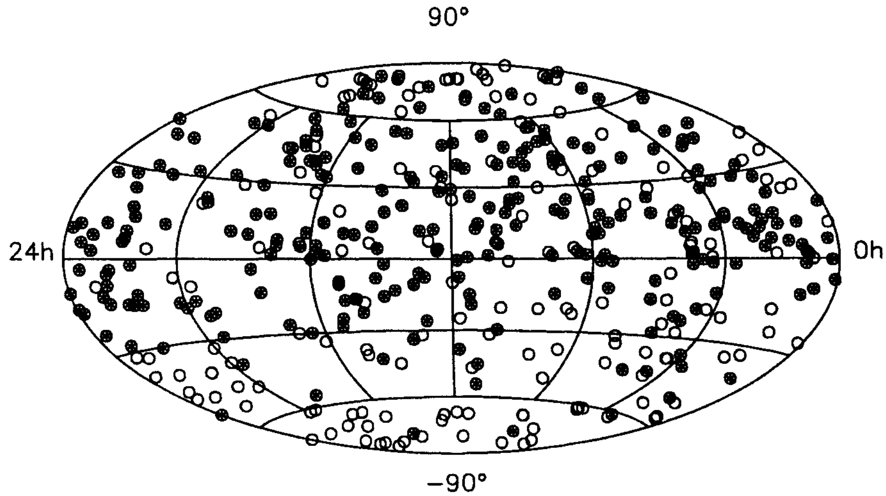
The IAU definitions of precession, sidereal time, and nutation were adopted as the underlying models. Because of insufficient knowledge of nutation, offset parameters with respect to the IAU standards for nutation in obliquity and longitude were solved for in each experiment. The degeneracy of the adjustment process with respect to these offset parameters was fixed by selecting 1993 February 12 as the reference day, adopting the standards on that day without modification. All determined nutation offset parameters are thus with respect to the pole of that reference day. Data from different epochs were therefore not combined using the standard models but rather through the sources observed in common.

The zero point of right ascension was fixed by arbitrarily adopting the J2000.0 right ascension of 0420-014 to define the equinox of the solution. This source was chosen primarily because of its good observing history (~ 21,000 observations) and its proximity to the celestial equator.

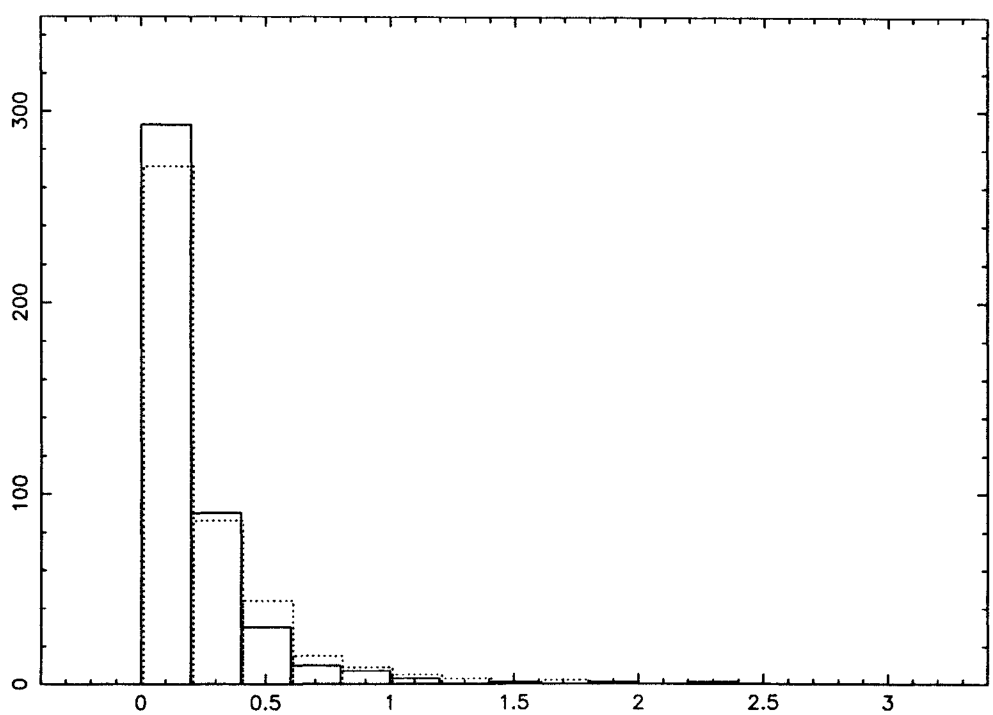
Finally, the source coordinates were rotated into the system of the IERS using the USNO n9409 celestial reference frame. The relative orientation of the frames (three rotation angles for the three axes) defined by these solutions was obtained by a least-squares adjustment between common sources. The resulting three rotation parameters were then used to transform all positions from our solution into the system of the IERS. Consequently, the RORF94 positions are consistent with the IERS celestial reference system. However, there remains an ~0.3 mas rotation in right ascension between the RORF94 positions and the current 1994 IERS frame. This rotation is presumably a consequence of the different method used here to construct the celestial frame but is well within the year to year variations in the IERS frame.

Parametrization of the RORF94 solution.

MODELS:	
	Solar System: PEP planetary ephemeris
	Precession/sidereal time: IAU 1984
	Solar relativistic deflection of light: IERS Standards
	Solid Earth tides: IERS Standards
	Ocean loading: IERS Standards
	Sub-diurnal Earth orientation
CALIBRATIONS:	
Troposphere	MTTDRFLY using meteorological data
Ionosphere	Simultaneous S/X observations
Instrumental	Length of timing signal/phase cal cable
ADJUSTED PARAMETERS:	
Global	Source positions
Arc	Station positions
	Nutation offsets in longitude and obliquity
	Polynomial clocks
	Zenith atmosphere delays
	Constrained atmosphere rates
MISCELLANEOUS:	
Elevation cutoff	7.0 degrees
Reference day	1993 February 12
Data type	Group delays and phase delay rates
Observations	1,015,292



Distribution over the sky of the 436 extragalactic radio sources of the celestial frame RSC(USNO) 95 R 00. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(USNO) 95 R 00.

EARTH ORIENTATION RESULTS FROM THE U.S. NAVAL OBSERVATORY VLBI PROGRAM

USNO 95 R 04, 05

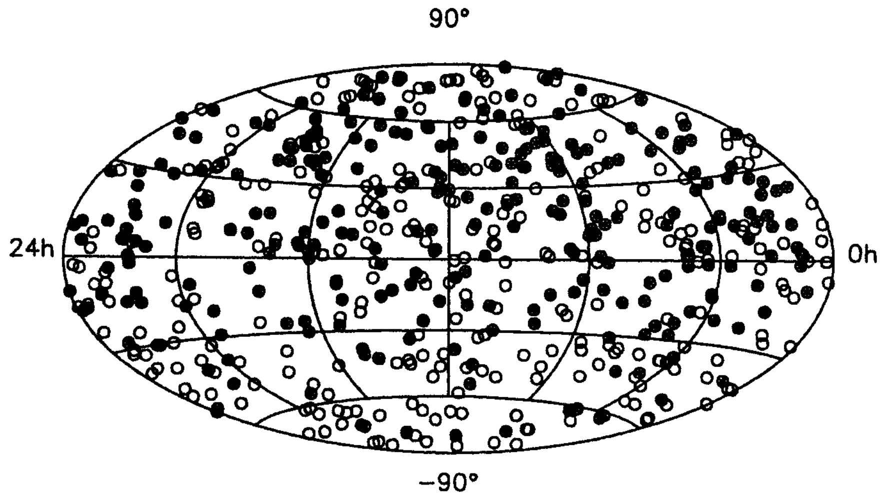
T.M. Eubanks, B.A. Archinal, M.S. Carter, F.J. Josties, D.N. Matsakis, and D.D. McCarthy, U.S. Naval Observatory, Washington, D.C., 20392-5100

Technical description of solution USNO 95 R 04

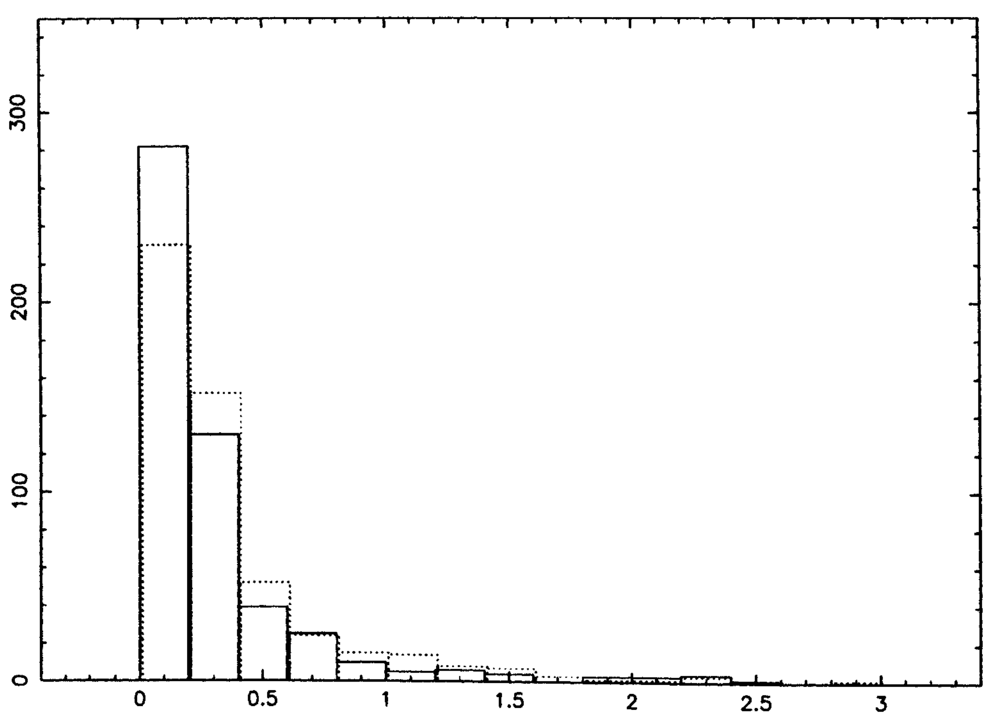
1 - Technique:	VLBI
2 - Analysis Center:	USNO
3 - Software used:	Calc. 7 - 6
4 - Data span:	
5 - Celestial Reference Frame:	RSC(USNO) 95 R 04
a - Nature:	extragalactic
b - Definition of the orientation:	Mean 50 sources in Right Ascension. Indirectly through mean IERS Bull. A values for nutation.
6 - Terrestrial Reference Frame:	SSC(USNO) 95 R 04
a - Relativity scale:	geocentric
b - Velocity of light:	299 792 458 m/s
c - Geogravitational constant:	
d - Permanent tidal correction:	No
e - Definition of the origin:	Mean of 12 stations positions in ITRF-93
f - Definition of the orientation:	Mean IERS Bull. A values for UT1 and polar motion
g - Reference epoch:	1 January 1993
h - Tectonic plate model:	1995 - 4 empirical model
i - Constraint for time evolution:	Mean of 12 station velocities with the Nuvel model as a priori

7 - Earth Orientation:
- a - A priori nutation model:
- b - Short-period tidal variations in x, y, UT1:

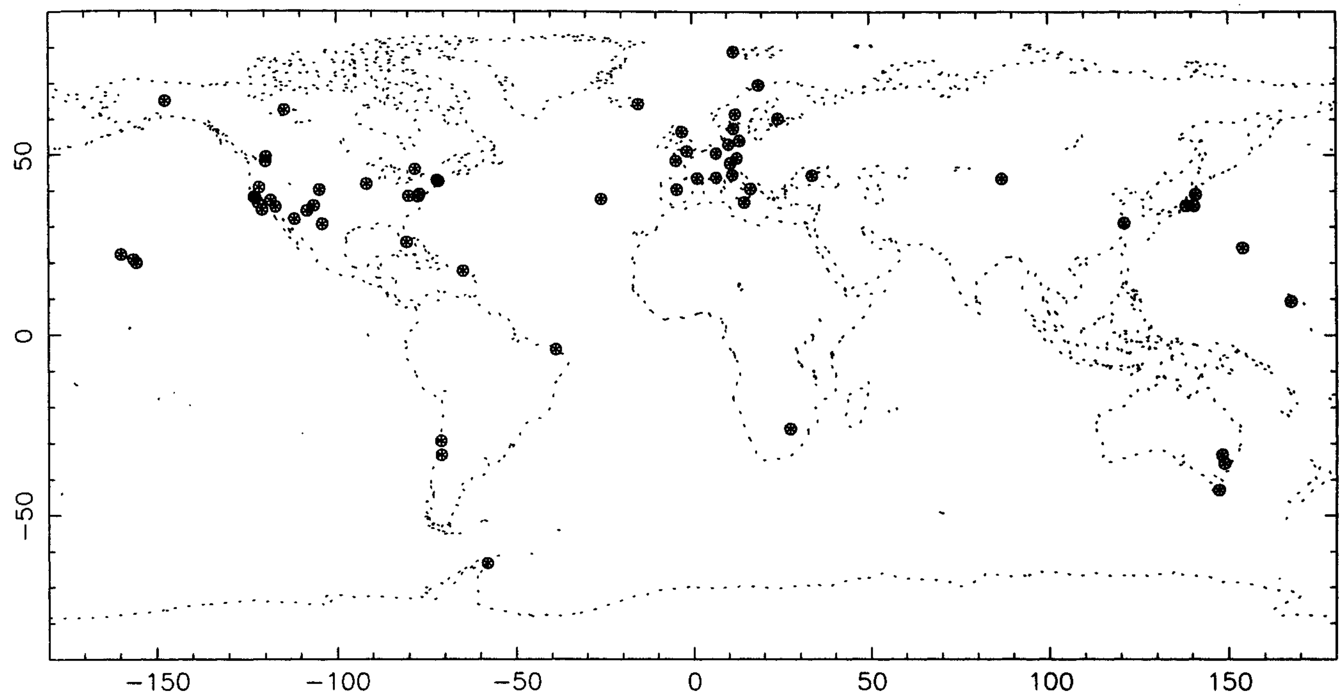
8 - Estimated Parameters
- a - Celestial Frame:
- b - Terrestrial Frame:
- c - Earth Orientation:
- d - Others:



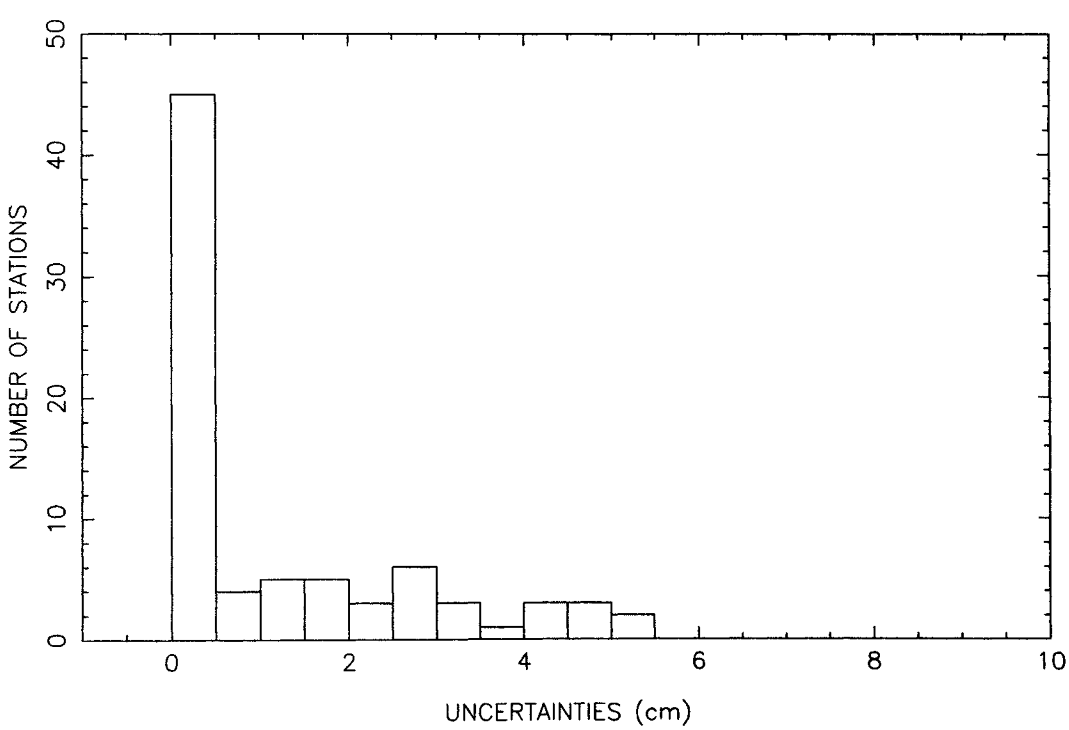
Distribution over the sky of the 536 extragalactic radio sources of the celestial frame RSC(USNO) 95 R 04. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(USNO) 95 R 04. 44 radio sources with uncertainties larger than 0.003" are not shown.



Distribution of the 65 sites of the terrestrial frame SSC(USNO) 95 R 04.



Distribution of the uncertainties (quadratic mean of $\sigma_x, \sigma_y, \sigma_z$) for the 81 stations of the terrestrial frame SSC(USNO) 95 R 04. 1 station with uncertainty larger than 10 cm is not shown.

EOP(USNO) 95 R 04 From Nov 1979 to Jul 1995

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

YEAR	X		Y		UT1		δψ		δε	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
1979	1	1.00	1	0.97	1	0.52	1	2.09	1	1.05
1980	19	0.53	19	0.55	19	0.26	19	0.89	19	0.43
1981	7	0.76	7	1.64	7	0.53	7	0.97	7	0.54
1982	16	0.80	16	0.79	16	0.37	16	1.43	16	0.60
1983	17	1.11	17	2.04	17	0.77	17	2.13	17	0.74
1984	87	0.57	87	0.56	87	0.30	87	0.93	87	0.40
1985	92	0.36	92	0.36	92	0.20	92	0.59	92	0.26
1986	107	0.35	107	0.32	107	0.19	107	0.55	107	0.24
1987	136	0.34	136	0.31	136	0.18	136	0.50	136	0.23
1988	133	0.27	133	0.27	133	0.15	133	0.44	133	0.18
1989	167	0.23	167	0.22	167	0.11	167	0.39	167	0.16
1990	203	0.21	203	0.21	203	0.10	203	0.35	203	0.14
1991	211	0.19	211	0.18	211	0.09	211	0.33	211	0.13
1992	236	0.16	236	0.16	236	0.08	236	0.29	236	0.12
1993	171	0.13	171	0.12	171	0.06	171	0.23	171	0.10
1994	164	0.10	164	0.08	164	0.05	164	0.19	164	0.08
1995	58	0.09	58	0.07	58	0.05	58	0.16	58	0.07

EOP(USNO) 95 R 05 From Dec 1993 to Jul 1995

Number of measurements per year and median uncertainties
Units : 0.0001" for UT1

YEAR	UT1	
	Nb	Sigma
1993	3	0.12
1994	213	0.18
1995	139	0.13

LUNAR LASER RANGING

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

FSG 95 M 01

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We have analyzed Lunar Laser Ranging (LLR) data acquired between 1970 and January, 1995. The observations are taken from the usual five sites: McDonald (three locations), Grasse and Haleakala; some normal points from Wettzell are added. All in all more than 9200 LLR measurements are used.

The constants adopted for the computations are those of the IAU recommendations resp. the IERS standards (McCarthy, 1992). For the 9-year, the annual, the half-year and the half-month period we used the values of Zhu *et al.* (1990).

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).

The input Earth orientation parameters are taken from a solution generated by R. Gross called COMB94; the tidally driven diurnal and semidiurnal UT1 variations have been added to the input UT1 file (Herring, 1993).

We determined the parameters of the Earth-Moon system by a least-squares fit to weighted observations. For the determination of 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, constraints indicated in Williams *et al.* (1991) have been used.

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. 1612 pairs were found. After having removed the bad ones 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) 95 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) 95 M 01.

Besides the parameters mentioned above, relativistic quantities have been determined: two metric parameters, the Nordtvedt parameter (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, one parameter indicating a violation of special relativity and one parameter which indicates the validity of the strong equivalence principle in the coupling of dark matter to the different compositions of Earth and Moon.

Values for all parameters are available on request.

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

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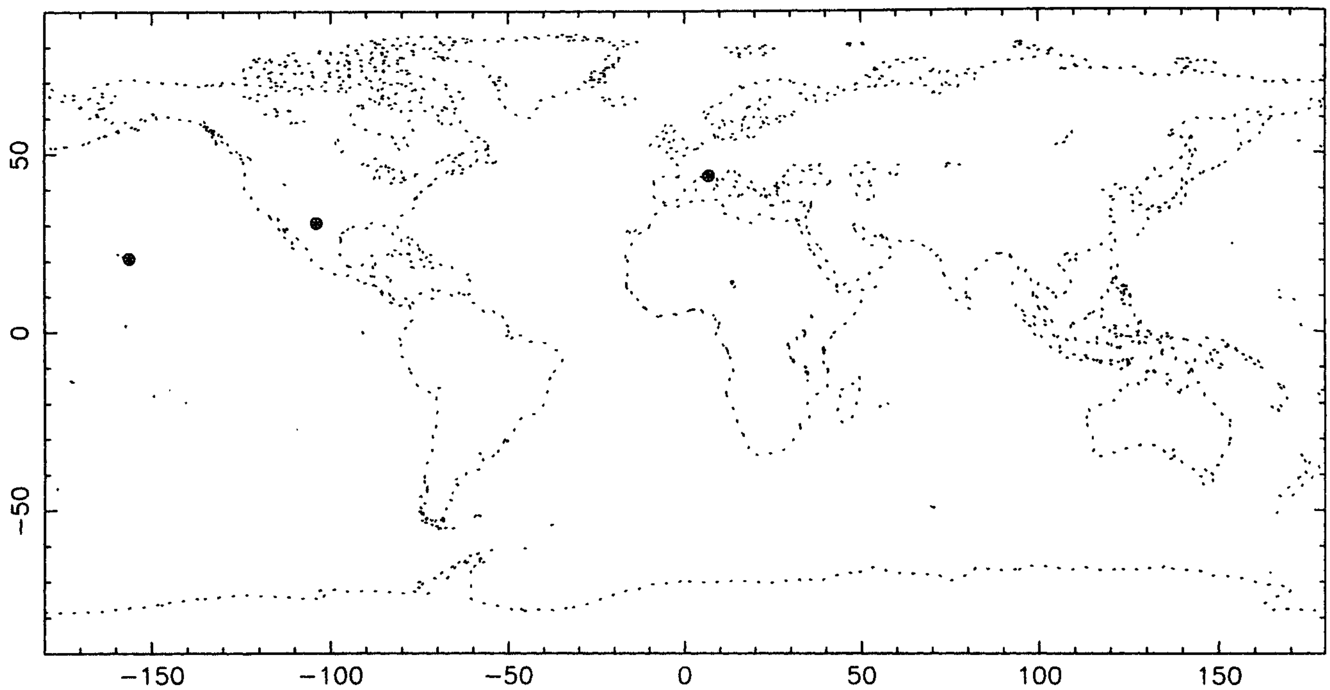
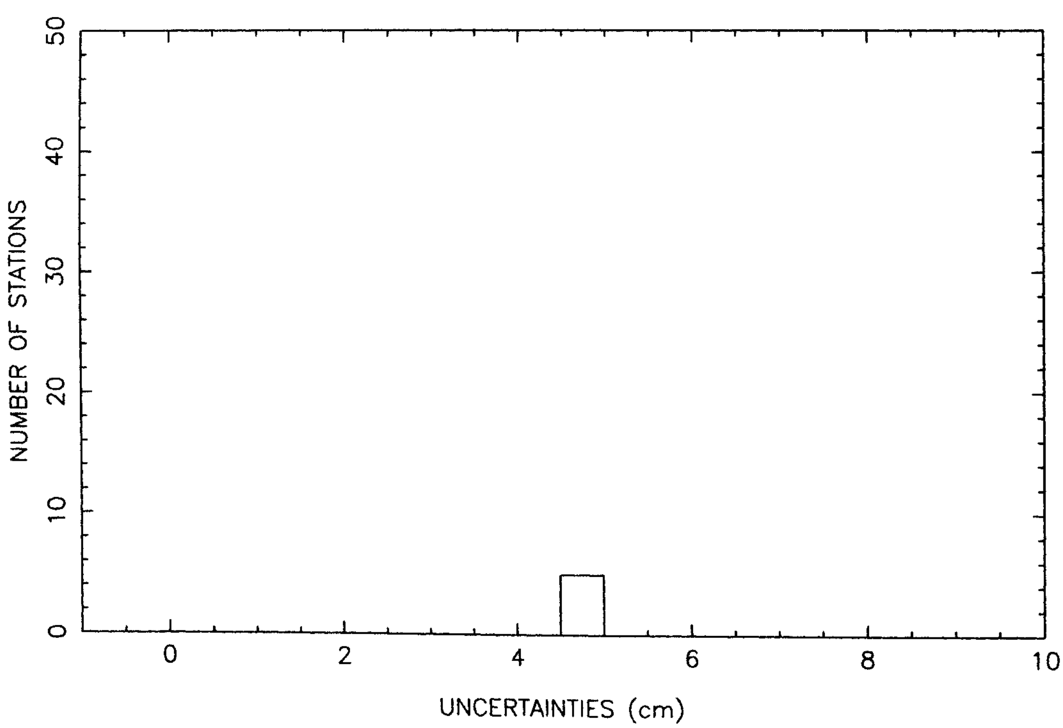
Technical description of solution FSG 95 M 01

1 - Technique:	LLR
2 - Analysis Center:	FSG/Techn. Univ. Munich
3 - Software used:	FSG LLR software
4 - Data span:	April 1970 - Jan 1995
5 - Celestial Reference Frame:	
a - Nature:	dynamical; own ephemeris program (initial values from DE200)
b - Definition of the Orientation:	referred to the equator and equinox of J2000 through the ephemeris
6 - Terrestrial Reference Frame:	SSC(FSG) 95 M 01
a - Relativity scale:	LE: relativistic geocentric frame
b - Velocity of light:	299792458 m/s
c - Geogravitational constant:	adjusted: 3.98600448 m^3/s^2 (geocentric)
d - Permanent tidal correction:	No
e - Definition of the origin:	by the geocenter through c10=0, c11=0, s11=0
f - Definition of the orientation:	EOP from 1970 to 1995 taken from a file of R. Gross (COMB94) which is aligned with the IERS system; daily corrections for UT0 and VOL are determined after the global fit
g - Reference epoch:	december 10, 1991 (MJD 48600)
h - Tectonic plate model:	NNR-NUVEL1
i - Constraint for time evolution:	fixed plate motion model (NNR-NUVEL1); estimation of UT1 and polar motion rates during the global solution
7 - Earth Orientation:	EOP(FSG) 95 M 01
a - A priori nutation model:	IAU(1980), values for the coefficients of the 9-year, annual, half-year and half-month period from Zhu et al. (1990)
b - Short-period tidal variations in x, y, UT1:	diurnal and semidiurnal tidal variations (M2, S2, N2, K1, O1, P1) in UT1 have been added (Herring, 1993), not in x and y
8 - Estimated parameters:	
a - Celestial Frame:	orbit of the Earth-Moon barycenter (X0, Y0, Z0, Xdot, Ydot, Zdot); lunar orbit (X0, Y0, Z0, Xdot, Ydot, Zdot)
b - Terrestrial Frame:	cartesian coordinates (X0, Y0, Z0); rates fixed (NNR-NUVEL1)
c - Earth Orientation:	UT0-UTC and variation of latitude VOL; luni-solar precession constant and the amplitudes of the 18.6-year nutation period (2 in-phase and 2 out-of-phase); rates for x, y, and UT1
d - Others:	lunar librations; reflector coordinates; lunar gravity; mass of the Earth-Moon system; lunar Love number and dissipation parameter; lag angle (lunar tidal acceleration); relativistic parameters



Distribution of the 3 sites of the terrestrial frame SSC(FSG) 95 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) 95 M 01.

EOP(FSG) 95 M 01 From Oct 1970 to Jan 1995

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	8	15.00	8	10.00
1971	21	15.00	21	10.00
1972	62	10.31	62	3.77
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	6.84
1977	70	15.00	70	10.00
1978	57	15.00	57	10.00
1979	62	15.00	62	10.00
1980	68	15.00	68	10.00
1981	29	15.00	29	10.00
1982	3	7.73	3	3.43
1983	6	15.00	6	10.00
1984	77	7.91	77	4.61
1985	175	7.84	175	3.45
1986	42	4.09	42	1.65
1987	39	3.87	39	1.27
1988	49	1.27	49	0.86
1989	51	1.34	51	0.87
1990	98	1.15	98	0.67
1991	63	1.36	63	0.62
1992	81	1.69	81	1.14
1993	100	1.53	100	0.80
1994	95	1.05	95	0.69
1995	13	0.88	13	0.69

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

JPL 95 M 01, 02

X X Newhall, J.G.Williams, and J.O.Dickey - Jet Propulsion Laboratory,
California Institute of Technology, Pasadena, California 91109-8099

Lunar Laser Ranging (LLR) data have been acquired and analyzed between April, 1970 and February, 1995. 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 March 2, 1994 have been submitted previously; 67 such values were derived from subsequent data acquired in 1994, and 21 values were obtained from early 1995 data, giving a total of 1433 values.

The full range data set comprises 9389 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.

Two EOP solutions were performed, one with the JPL ephemeris DE247/LE247, providing the set EOP (JPL) 95 M 01; the other solution was done with the recent ephemeris DE402/LE402, providing EOP (JPL) 95 M 02. The lunar librations were integrated simultaneously with the ephemerides.

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 has been solved for. 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 term 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. The precession and nutation corrections are:

	Solution 1 (DE247)	Solution 2 (DE402)
Δp	-3.3mas/yr	3.1mas/yr
$\Delta\varepsilon$	$1.7 \cos\Omega + 0.2 \sin\Omega$ mas	$1.4 \cos\Omega + 0.8 \sin\Omega$ mas
$\sin\varepsilon\,\Delta\psi$	$-1.6 \sin\Omega + 0.2 \cos\Omega$ mas	$-1.1 \sin\Omega + 0.6 \cos\Omega$ 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 mas, and the precession uncertainty is 0.3 mas/yr. Without the constraint these uncertainties would be larger.

The station locations resulting from the two solutions are called SSC(JPL) 95 M 01, for the case with DE247, and SSC(JPL) 95 M 02, for the case with DE402. The separations between the McDonald sites were constrained to survey values. The separation between the Haleakala transmitter and receiver also conforms to a survey. A range bias is estimated for Haleakala beginning in January, 1990.

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.

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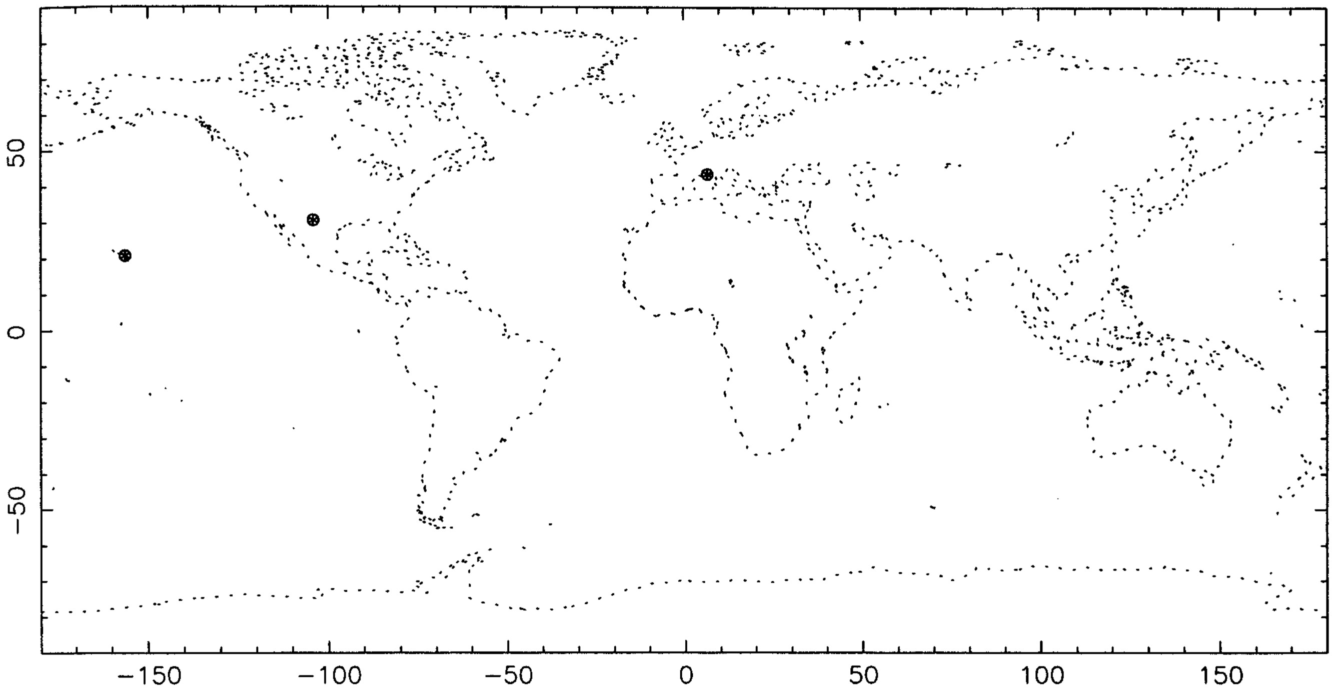
Technical description of solution JPL M 01

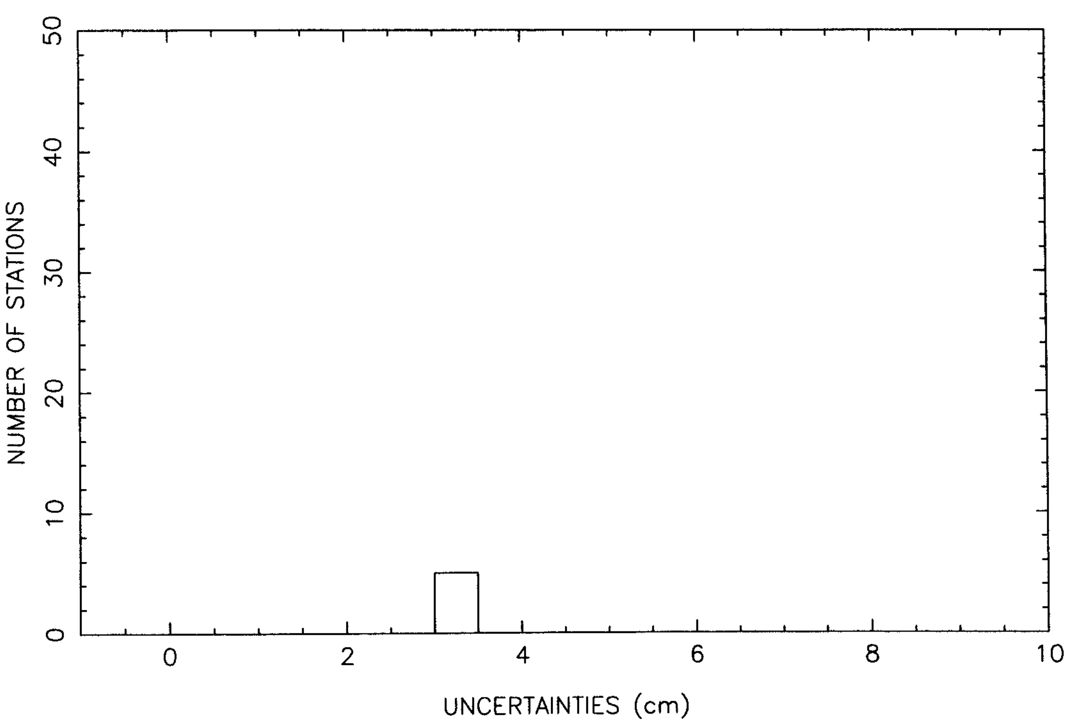
1 - Technique:	LLR
2 - Analysis center:	JPL
3 - Software used:	JPL LLR software
4 - Data span:	Apr 70 - Feb 95
5 - Celestial reference frame:	
a - Nature:	Dynamical
b - Definition of orientation:	DE 247 orbit
6 - Terrestrial reference frame:	SSC(JPL) 95 M 01
a - Relativity scale:	SSB
b - Velocity of light:	c = 299792458 m/sec
c - Geogravitational constant:	GM0 = 3.986004427 10^{14} m^3/s^2 value is from ephemeris solution and has been converted to local earth frame. GM0 does not influence the LLR station radii.
d - Permanent tidal correction:	Yes
e - Definition of the origin:	Geocenter (center of mass)
f - Definition of the orientation:	Input Earth rotation values from 1970 to early 1995 taken from a file from R. Gross (a version of COMB-94 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, precession/ nutation, etc., but final UT0/VOL values generated after the global fit.
g - Reference epoch:	January 1, 1991 (JD 2448257.5)
h - Tectonic plate model:	NNR-NUVEL1
i - Constraint for time evolution:	Plate motion was not adjusted. Solved for overall corrections to the UT1 and polar motion rates with respect to the input UT1/polar motion file.
7 - Earth orientation:	EOP(JPL) 95 M 01
a - A priori nutation model:	IAU (1980) plus corrections from ZMOA for in-phase 9.3 yr, annual, and semi-monthly coefficients plus semiannual in- and out-of phase corrections.
b - Short-period tidal variations in x, y, UT1:	Daily and subdaily variations in UT1 for M2, S2, N2, K1, O1, and P1 tides from Herring (1993). These fast variations are not in EOP file.
8 - Estimated parameters	
a - Celestial frame:	Orbit parameters.
b - Terrestrial frame:	Spherical station coordinates (rates fixed) from full data span. Differences between three McDonald sites are constrained to surveys.
c - Earth orientation:	Precession rate and 18.6 yr nutation coefficients estimated. Daily UT0 and VOL values are generated after global solution.
d - Others:	Lunar orientation, tidal acceleration, obliquity.

Technical description of solution JPL 95 M 02

1 - Technique:	LLR
2 - Analysis center:	JPL
3 - Software used:	JPL LLR software
4 - Data span:	Apr 70 - Feb 95
5 - Celestial reference frame:	
a - Nature:	Dynamical, but oriented to IERS celestial frame.
b - Definition of orientation:	DE 402 orbit is oriented to IERS frame.
6 - Terrestrial reference frame:	SSC(JPL) 95 M 02
a - Relativity scale:	SSB
b - Velocity of light:	c = 299792458 m/sec
c - Geogravitational constant:	GM0 = 3.986004425 10^{14} m^3s^2 value is from ephemeris solution and has been converted to local earth frame. GM0 does not influence the LLR station radii.
d - Permanent tidal correction:	Yes
e - Definition of the origin:	Geocenter (center of mass)
f - Definition of the orientation:	Input Earth rotation values from 1970 to early 1995 taken from a file from R. Gross (a version of COMB-94 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, precession/ nutation, etc, but final UT0/VOL values generated after the global fit.
g - Reference epoch:	January 1, 1991 (JD 2448257.5)
h - Tectonic plate model:	NNR-NUVEL1
i - Constraint for time evolution:	Plate motion was not adjusted. Solved for overall corrections to the UT1 and polar motion rates with respect to the input UT1/polar motion file.
7 - Earth orientation:	EOP(JPL) 95 M 02
a - A priori nutation model:	IAU(1980) plus corrections from ZMOA for in-phase 9.3 yr, annual, and semi-monthly coefficients plus semiannual in- and out-of phase corrections.
b - Short-period tidal variations in x, y, UT1:	Daily and subdaily variations in UT1 for M2, S2, N2, K1, O1, and P1 tides from Herring (1993). These fast variations are not in EOP file.
8 - Estimated parameters	
a - Celestial frame:	Orbit parameters.
b - Terrestrial frame:	Spherical station coordinates (rates fixed) from full data span. Differences between three McDonald sites are constrained to surveys.
c - Earth orientation:	Precession rate and 18.6 yr nutation coefficients estimated. Daily UT0 and VOL values are generated after global solution.
d - Others:	Lunar orientation, tidal acceleration, obliquity.



Distribution of the 3 sites of the terrestrial frame SSC(JPL) 95 M 01



Distribution of the uncertainties (quadratic mean of $\sigma_x, \sigma_y, \sigma_z$) for the 5 stations of the terrestrial frame SSC(JPL) 95 M 01.

From Apr 1970 to Feb 1995

EOP(JPL) 95 M 01

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

YEAR	φ Nb	φ Sigma	UT0 Nb	UT0 Sigma
1970	15	13.91	15	9.81
1971	34	12.55	34	7.38
1972	72	8.24	72	5.06
1973	102	13.95	102	7.51
1974	69	11.21	69	6.40
1975	87	10.31	87	6.87
1976	64	8.44	64	5.10
1977	68	6.61	68	4.02
1978	49	8.20	49	5.75
1979	65	6.67	65	4.73
1980	68	5.90	68	4.09
1981	45	8.24	45	4.26
1982	6	8.30	6	4.97
1983	0		0	
1984	26	4.29	26	2.26
1985	111	5.72	111	2.49
1986	28	3.40	28	1.60
1987	19	2.78	19	1.06
1988	71	1.97	71	1.01
1989	42	1.50	42	0.92
1990	89	1.42	89	0.90
1991	56	1.31	56	0.73
1992	53	1.23	53	0.82
1993	82	1.42	82	1.15
1994	87	0.91	87	0.80
1995	21	1.01	21	0.80

EOP(JPL) 95 M 02

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

YEAR	φ Nb	φ Sigma	UT0 Nb	UT0 Sigma
1970	15	13.93	15	9.82
1971	34	12.56	34	7.39
1972	72	8.25	72	5.06
1973	102	13.96	102	7.52
1974	69	11.22	69	6.41
1975	87	10.32	87	6.87
1976	64	8.45	64	5.11
1977	68	6.62	68	4.03
1978	49	8.21	49	5.76
1979	65	6.68	65	4.74
1980	68	5.91	68	4.09
1981	45	8.25	45	4.27
1982	6	8.30	6	4.98
1983	0		0	
1984	26	4.29	26	2.26
1985	111	5.72	111	2.49
1986	28	3.40	28	1.60
1987	19	2.78	19	1.06
1988	71	1.98	71	1.01
1989	42	1.50	42	0.92
1990	89	1.42	89	0.90
1991	56	1.31	56	0.73
1992	53	1.23	53	0.82
1993	82	1.42	82	1.15
1994	87	0.91	87	0.80
1995	21	1.01	21	0.80

DETERMINATION OF UNIVERSAL TIME BY LUNAR LASER RANGING

SHA 95 M 01

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

Lunar Laser Ranging (LLR) data have been analyzed during JD 2447187.0 - JD 2449709.0. These data set of McDonald (71111, 71112), Grasse (1910) and Haleakala (56610) contain 4111 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 NUVEL model. The base epoch for plate motion is January 1,1993. The relativistic effects (propagation correction, scale factor and Lorentz effect) are considered. The planetary ephemeris DE245/LE245 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, third degree and order lunar potential, and orbit parameters of the Earth-Moon system were estimated.

The post-fit residuals are analysed to obtain 449 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) 95 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 observational equation.

Acknowledgments

We wish to thank Dr. Myles Standish and Dr. Veillet who supplied the planetary ephemeris DE245/LE245 and the global data of lunar laser ranging.

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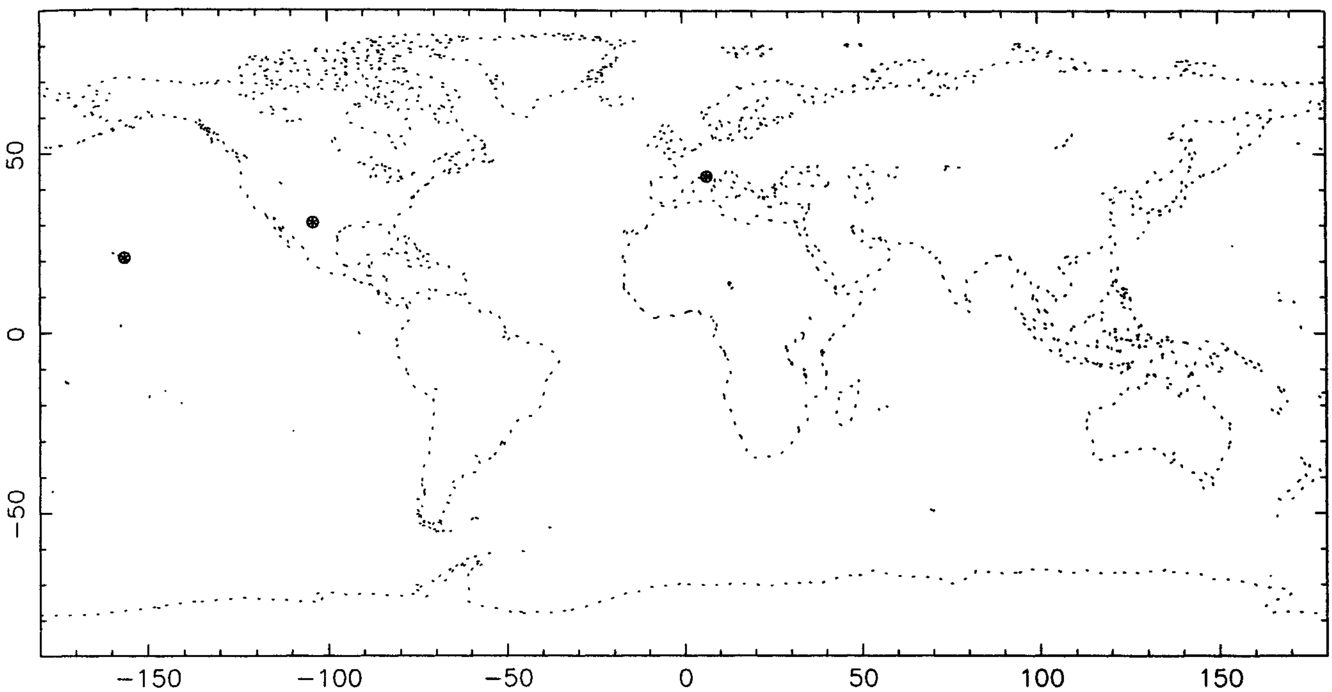
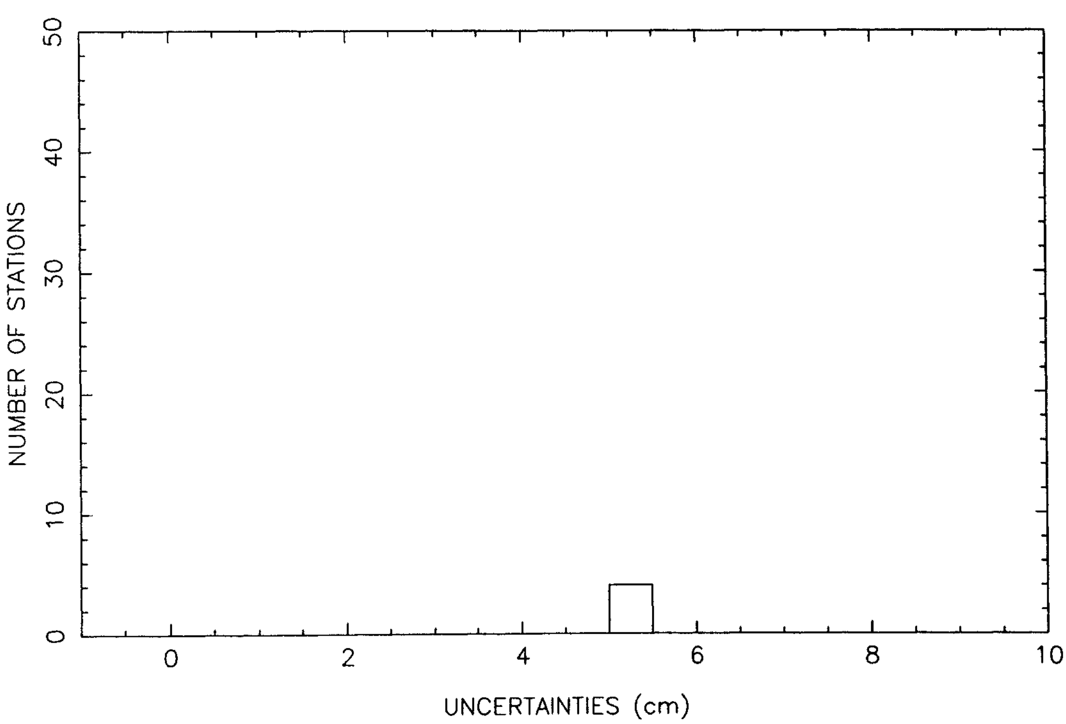
Technical description of solution SHA 95 M 01

1 - Technique:	LLR
2 - Analysis Center:	SHA
3 - Software used:	SHA LLR software
4 - Data span:	
5 - Celestial Reference Frame:	
a - Nature:	Dynamical
b - Definition of the orientation:	
6 - Terrestrial Reference Frame:	SSC(SHA) 95 M 01
a - Relativity scale:	SSB
b - Velocity of light:	299792458
c - Geogravitational constant:	3.986004418 10^{14}
d - Permanent tidal correction:	No
e - Definition of the origin:	Geocenter (center of mass)
f - Definition of the orientation:	EOP from 1988 to 1994 taken from IERS Circular B
g - Reference epoch:	1993.0
h - Tectonic plate model:	NUVEL
i - Constraint for time evolution:	Constrained to NUVEL
7 - Earth Orientation:	EOP(SHA) 95 M 01
a - A priori nutation model:	
b - Short-period tidal variations in x, y:	
8 - Estimated parameters:	
a - Celestial Frame:	
b - Terrestrial Frame:	Cylindrical coordinates of stations (rates fixed)
c - Earth Orientation:	
d - Others:	



Distribution of the 3 sites of the terrestrial frame SSC(SHA) 95 M 01



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 4 stations of the terrestrial frame SSC(JPL) 95 M 01.

EOP(SHA) 95 M 01 From Jan 1988 to Dec 1994

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

YEAR	UT0	
	Nb	Sigma
1988	58	1.40
1989	55	1.40
1990	87	1.40
1991	56	1.25
1992	45	1.00
1993	75	1.40
1994	73	1.20

UT0 AND VARIATION OF LATITUDE DETERMINATION FROM LUNAR LASER RANGING OBSERVATIONS FOR 1969-1994

UTXMO 95 M 01

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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, 1995. A total of 9751 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), the CERGA station in Grasse, France, and the Wettzell Laser Ranging Station in Germany 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 976 station/reflector pair estimations of UT0-UTC including 81 UT0 estimates, on 69 nights, in 1994. This is about the same as for 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. We estimated a piecewise linear spline for the polar motion components and UT1 to model long period deficiencies in the series. 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 EOP corrections contained in the splines, and the a priori EOP 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 post-fit range residuals, for the entire span of data, was 4.6 cm. The weighted rms of the post-fit residuals for the 822 normal points obtained by the three active stations during 1994 was 2.8 cm.

We have compared our UT0 and variation of latitude series with the NAVNET 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 NAVNET UT1 and polar motion values. Interpolation of the NAVNET 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 1995.2).

Table 1.Comparison between University of Texas McDonald Observatory LLR UT0R and variation of latitude (DPhi) and NAVNET VLBI values. The period of comparison is 1986.5 to 1995.2. The epoch of the linear fit is 1990.8.

Station		Bias (mas)	Slope (mas/yr)	WRMS (mas)	N
CERGA	DUT0R:	1.26 +/- 0.10	0.77 +/- 0.05	3.04	362
	DPHI:	-1.54 +/- 0.10	2.31 +/- 0.04	3.36	
MLRS	DUT0R:	0.52 +/- 0.41	-1.53 +/- 0.14	3.36	83
	DPHI:	0.46 +/- 0.46	0.04 +/- 0.15	2.83	
Maui	DUT0R:	3.31 +/- 0.73	0.79 +/- 0.26	3.10	43
	DPHI:	2.78 +/- 0.98	0.62 +/- 0.36	3.50	

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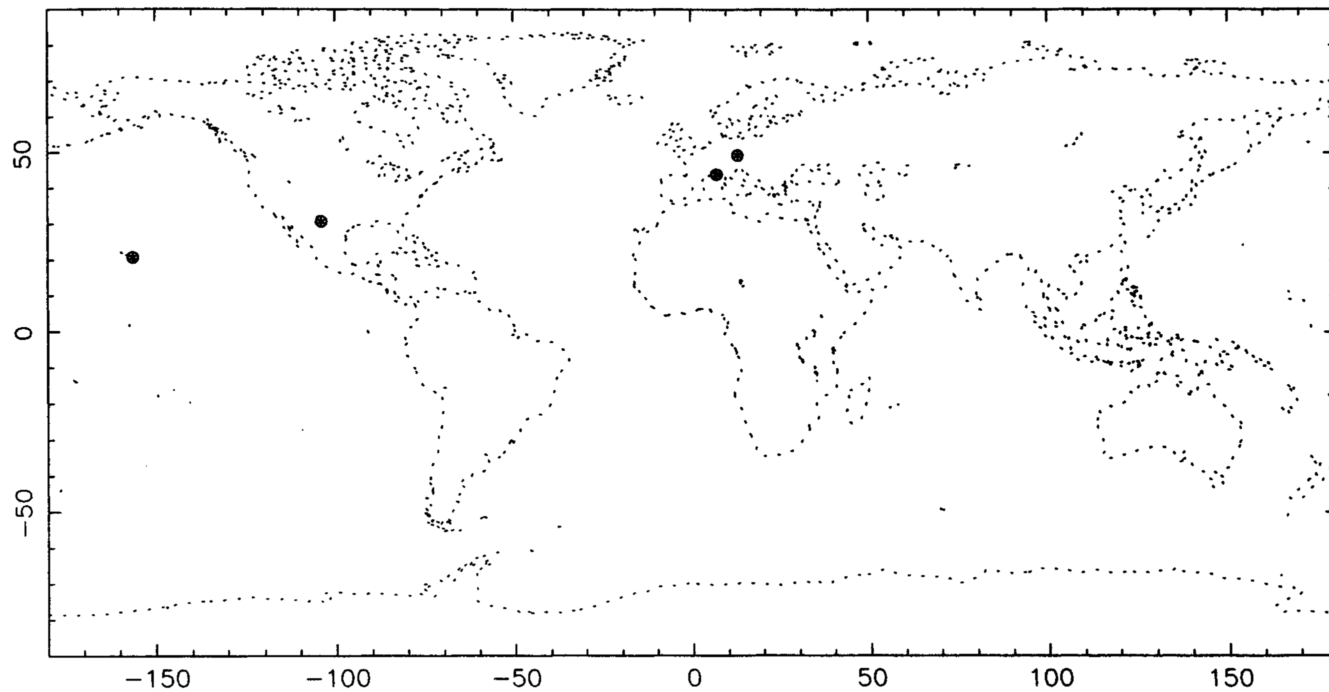
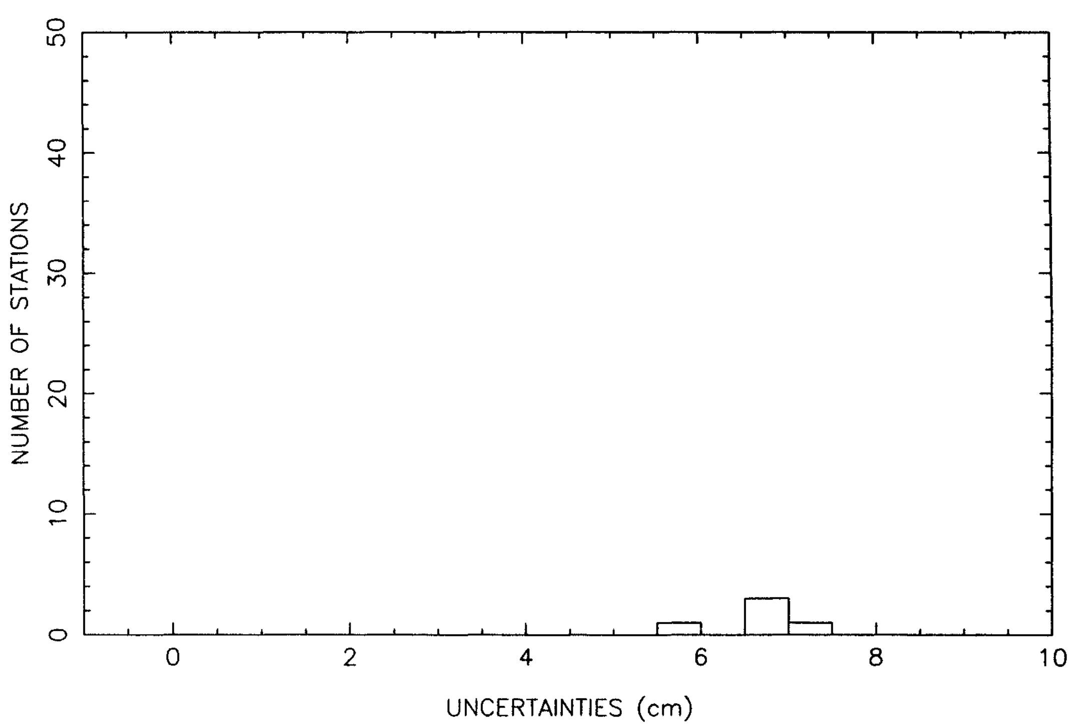
Technical description of solution UTXMO 95 M 01

1 - Technique:	LLR
2 - Analysis Center:	UTXMO
3 - Software used:	PEP
4 - Data span:	Sep 69 - Mar 95
5 - Celestial Reference Frame:	
a - Nature:	Dynamical. The EMbary and lunar ephemerides were estimated.
b - Definition of the orientation:	The node of the EMbary orbit was fixed to the MIT ITR-78 ephemeris to tie the longitude of the celestial reference frame.
6 - Terrestrial Reference Frame:	SSC(UTXMO) 95 M 01
a - Relativity scale:	SSB
b - Velocity of light:	299792458
c - Geogravitational constant:	3.986004415 (geocentric)
d - Permanent tidal correction:	No
e - Definition of origin:	Geocenter
f - Definition of orientation:	Fixed to CSR EOP(CSR) 94 L 01 series at 11 Jan 1985
g - Reference epoch:	1984.0
h - Tectonic plate model:	AM0-2
i - Constraint for time evolution:	Constrained to AM0-2
7 - Earth orientation:	EOP(UTXMO) 95 M 01
a - A priori nutation model:	IAU(1980)
b - Short-period tidal variations in x, y, UT1:	No
8 - Estimated Parameters:	
a - Celestial Frame:	EMbary orbit (node fixed), lunar orbit, GM, lunar librations, third order gravitational potential of the moon, retro-reflector coordinates
b - Terrestrial Frame:	Cylindrical station coordinates
c - Earth Orientation:	Precession constant, 14d, 183d, 365d, and 18.6 yr nutation amplitudes, UT0, $d\varphi$
d - Others:	Range biases for McDonald 2.7m, CERGA, Maui, and Wettzell stations



Distribution of the 4 sites of the terrestrial frame SSC(UTXMO) 95 M 01



Distribution of the uncertainties (quadratic mean of $\sigma_x, \sigma_y, \sigma_z$) for the 6 stations of the terrestrial frame SSC(UTXMO) 95 M 01. 1 station with uncertainty larger than 10 cm is not shown.

EOP(UTXMO) 95 M 01 From Oct 1970 to Jul 1995

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

YEAR	φ Nb	φ Sigma	UT0 Nb	UT0 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	23	6.90	23	4.54
1980	6	6.25	6	3.75
1981	4	18.25	4	4.02
1982	0		0	
1983	6	5.10	6	4.20
1984	35	4.80	35	4.07
1985	103	7.50	103	3.97
1986	24	6.50	24	3.22
1987	21	8.70	21	2.91
1988	56	4.80	56	2.67
1989	43	4.10	43	2.84
1990	77	4.10	77	2.79
1991	57	3.60	57	2.37
1992	51	4.00	51	2.60
1993	87	3.90	87	3.37
1994	81	2.50	81	2.81
1995			64	2.60

GLOBAL POSITIONING SYSTEM

1994 ANNUAL REPORT OF THE CODE PROCESSING CENTER OF THE IGS

CODE 95 P 01, 02

M. Rothacher, G. Beutler, E. Brockmann, L. Mervart, R. Weber (Astronomical Institute, Bern), U. Wild, A. Wiget (Federal Office of Topography, Wabern), H. Seeger (Institute for Applied Geodesy, Frankfurt), C. Boucher (Institut Géographique National, Paris)

CODE, the Center for Orbit Determination in Europe, is a joint venture of four European Institutions. It is located at the University of Bern, the computations are performed on a cluster of VAX/ALPHA processors. The software used is the Bernese GPS Software Version 3.6, which is continuously improved to meet the steadily growing demands of the IGS processing.

Markus Rothacher is the head of the CODE processing and development team, Robert Weber is responsible for the CODE solutions since July 1993. We refer to (Rothacher *et al*, 1994) for a general description of the processing at the CODE processing center. Here we only present the development which took place in 1994.

Again the number of stations included in our processing was considerably growing (from 38 stations at the end of 1993 to 49 stations at the end of 1994). The fact that 17 of "our" 49 stations lie in Europe underlines that CODE puts the emphasis on Europe in its contribution to the ITRF. The ERP series and the coordinates sent to the IERS in 1995 are based on the ITRF93. The same 13 stations were kept fixed in 1994 as in 1993 to produce the ERPs results (Rothacher *et al.*, 1994).

The program ADDNEQ, our routine stacking normal equations (Rothacher *et al*, 1994) was considerably generalized in 1994. Today it is the central tool of the CODE processing center of the IGS:

- ADDNEQ may now be used to form n-day arcs, n >= 2, from one-day arcs (Beutler *et al*, 1995). This new development saves many hours of CPU in the daily routine.

- More troposphere parameters (12 per station and day) are set up in the one-day solutions. ADDNEQ allows it to produce solutions based on 2-, 4- ,6- ,12-, and 24-hour troposphere intervals (per station and day).

- ADDNEQ may now handle nutation parameters: First derivatives of $d\varepsilon$ and $d\psi$ may be extracted from ADDNEQ. Time series are (internally) available since 1 January 1994.

- The capabilities to change the reference frame (e.g. from ITRF92 to ITRF93) are now fully implemented and active. As soon as a new reference frame becomes available new solutions (coordinates, orbits, etc) may be extracted easily from ADDNEQ back to day 200 of year 1993.

It is also worth mentioning that since 1 January 1994 the troposphere parameters are stored in a user-friendly form. They are available for atmosphere studies.

Ambiguity resolution on long baselines was studied by Mervart (1994), a solution based on about 70%-80% fixed ambiguities is produced in a fully automatic way in parallel to our official solutions since October 1994.

The orbit model was studied already in 1993 (Beutler *et al.*, 1994). The program ORBIMP, using an improved radiation pressure model, is used for the long arc analysis by the IGS analysis center coordinator (Beutler *et al.*, 1993). At present we are systematically analysing the mean orbital elements, the series of radiation pressure parameters, and the series of stochastic parameters generated since mid 1992. We expect that this analysis will contribute to a new IGS radiation pressure model in 1995.

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Technical description of solution CODE 95 P 01

1 - Technique: GPS

2 - Analysis Center: CODE

3 - Software used: Bernese GPS Software Version 3.6

4 - Data span: 19 July 1993 (doy 200) - 1 March 1995

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

6 - Terrestrial Reference Frame: SSC(IERS) 94 C 02
- a - Relativity scale: Local Earth
- b - Velocity of light: 299792458 m/s
- c - Geogravitational constant: 398.6004415 10^{12} m^3/s^2
- d - Permanent tidal correction: yes
- e - Definition of origin: origin of ITRF93
- f - Definition of orientation: non-rotation constraint
- g - Reference epoch: ---
- h - Tectonic plate model: ITRF93 velocity field
- i - Constraint for time evolution: ITRF93 velocity field

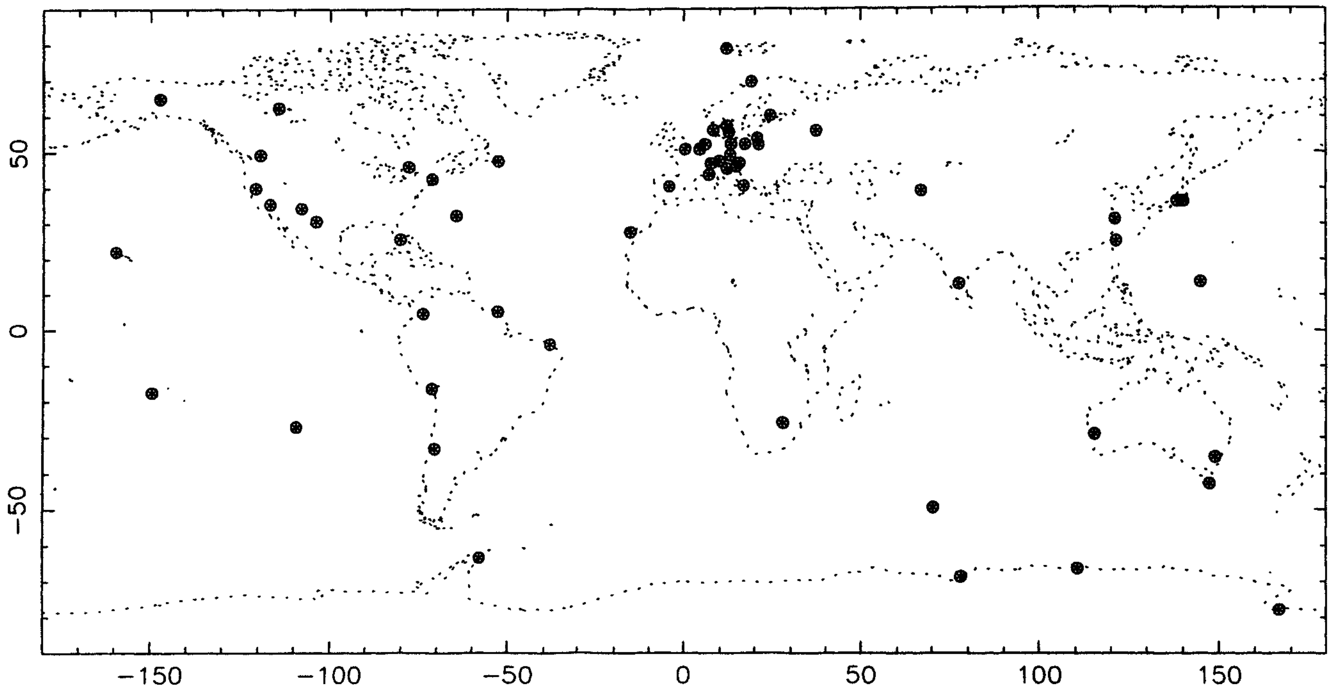
7 - Earth orientation: EOP(CODE) 95 P 01
- a - A priori nutation model: IAU 1980
- b - Short-period tidal variations in x, y, UT1: none

8 - Estimated Parameters:
- a - Celestial Frame: ---
- b - Terrestrial Frame: coordinates of free stations

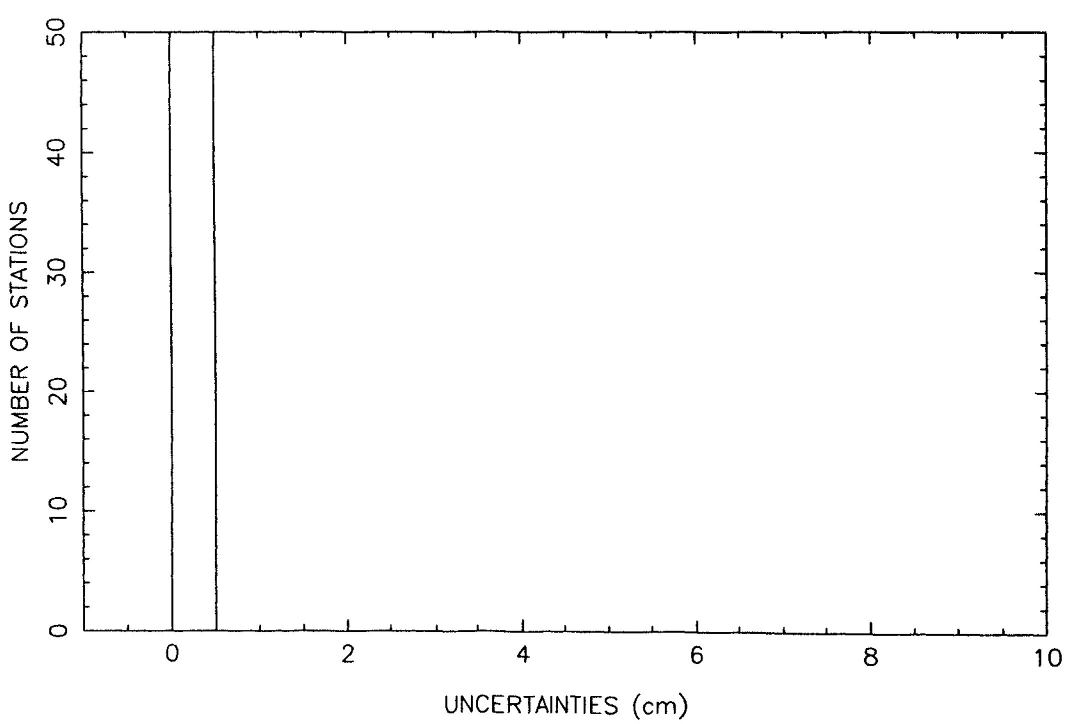
c - Earth Orientation:	x, y, UT1-UTC drift, and drifts in x, y
d - Others:	zenith troposphere delays (4 per day and station), orbit parameters (8 per satellite), ambiguities, stochastic acceleration parameters for eclipsing satellites.

Technical description of solution CODE 95 P 02

1 - Technique:	GPS
2 - Analysis Center:	CODE
3 - Software used:	Bernese GPS Software Version 3.6
4 - Data span:	01 April 1993 (doy 091) - 1 March 1995
5 - Celestial Reference Frame:	
a - Nature:	dynamical
b - Definition of the orientation:	---
6 - Terrestrial Reference Frame:	SSC(CODE) 95 P 02
a - Relativity scale:	Local Earth
b - Velocity of light:	299792458 m/s
c - Geogravitational constant:	398.6004415 10^{12} m^3/s^2
d - Permanent tidal correction:	yes
e - Definition of origin:	origin of ITRF93
f - Definition of orientation:	non-rotation constraint
g - Reference epoch:	16 March 1994
h - Tectonic plate model:	horizontal component estimated, vertical component used from ITRF93
i - Constraint for time evolution:	WETT fixed on ITRF93 velocity, stations with a short observation period are constrained to ITRF93
7 - Earth orientation:	EOP(CODE) 95 P 02
a - A priori nutation model:	IAU 1980
b - Short-period tidal variations in x, y, UT1:	none
8 - Estimated Parameters:	
a - Celestial Frame:	---
b - Terrestrial Frame:	coordinates and velocities of all stations
c - Earth Orientation:	x, y, UT1-UTC drift, and drifts in x, y
d - Others:	zenith troposphere delays (4 per day and station), orbit parameters (8 per satellite), ambiguities, stochastic acceleration parameters for eclipsing,satellites.



Distribution of the 60 sites of the terrestrial frame SSC(CODE) 95 P 02.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 69 stations of the terrestrial frame SSC(CODE) 95 P 02.

EOP(CODE) 95 P 01 From Jul 1993 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
1993	166	0.04	166	0.04	166	0.03
1994	365	0.04	365	0.03	365	0.03
1995	210	0.02	210	0.03	210	0.02

1995 GPS DATA PROCESSING AT THE EMR ANALYSIS CENTRE

EMR 95 P 02

J. Kouba, R. Ferland, P. Tetreault, J. Popelar, Geodetic Survey Division (GSD), Geomatics Canada, Natural Resources Canada (NRCan) (Formerly: Energy Mines and Resources (EMR)), 615 Booth St., Ottawa, Ont. K1A OE9

Since August 1992 the GSD's Master Active Control System (MACS) Centre has been processing GPS data from six Canadian ACS stations augmented by up to 16 stations of the International GPS Service for Geodynamics (IGS) global station network. Typically there were 25 GPS satellites observed and their precise ephemeris generated daily during 1994. The GIPSY II/ OASIS GPS software system developed by the Jet Propulsion Laboratory has been adapted to obtain daily orbit, EOP and station coordinate solutions. As recommended by IGS, 13 stations (ALGO, YELL, FAIR, GOLD, SANT, TROM, KOSG, WETT, MADR, HART, HART, TIDB, YAR1) were constrained at the ITRF92 coordinates of the date, utilizing the ITRF92 station velocities. The adopted constants, gravity and radiation pressure models conform to the IGS/IERS standards (McCarthy, 1992). The global ocean loading model due to Pagiatakis (1982) has been adopted.

Daily 1994 GPS Processing:

The EMR processing is based on undifferenced phase and smoothed pseudorange data at 7.5 minutes sampling intervals using 15 degree elevation angle cut off. Both phase and pseudorange observations are considered uncorrelated and weighted using an exponential elevation angle function. Some stations (e.g. STJO, YELL) have higher pseudorange noise due to multipath and are being weighted accordingly. We have also enhanced the GIPSY II software to facilitate different weighting of satellites data, data segment deletion and corrections of satellite dependent pseudorange biases. This improved results for AS pseudorange data since AS was permanently introduced on Jan. 31, 1994.

The daily solutions generate 24h arcs without any overlap. For each 24h arc the initial a priori state vector is taken from the previous day solution and propagated to the beginning of the current day and augmented by stochastic orbit sigmas of about 0.2m and 0.1mm/s, making the estimation process self contained. Broadcast orbits are used only when introducing or re-introducing a satellite. This approach also facilitates an estimation of UT1-UTC. Due to collinearity between UT1 and the R.A. of the ascending orbit nodes, the estimated UT1-UTC may contain both the UT1 changes as well as the orbit node errors common to all satellites, with sigmas and correlation characteristic of a random walk process. Jan. 2, 1994 UT1-UTC was initialized to a Bull. A value and a continuous UT1-UTC series has been maintained since.

The terrestrial reference frame position/orientation, and to a large extend the scale of the EMR orbit/EOP solutions are nominally those of ITRF92 (current epoch) as realized through the set of the 13 stations constrained at the ITRF92 SSC and SSV. The reported EOP sigmas are the formal sigmas as obtained from the adjustment. The repeatability of position solutions indicates that the formal sigma may be too optimistic, and need to be multiplied by a factor of 2 or 3. More information on the EMR daily processing is provided in Tetreault *et al.* (1995).

Batch Reprocessing:

All the archived 1994 daily solutions were retrieved and subjected to additional statistical testing/editing with emphasis on improving daily station solutions. The a priori (ITRF92) coordinate and sigma constraints at the 13 stations were rigorously removed and 10m sigma constraints were introduced to prevent numerical instability. These unconstrained variance-covariance matrices and the solutions for station coordinates, EOP were then combined into a single annual solution for station coordinates, velocities and daily EOP. The orbit state vector and other unknowns contained in the daily solutions were first rigorously eliminated from the solutions. The final solution is practically unconstrained and approximates a rigorous addition of the reduced normal matrices. It produced a consistent set of station coordinates (at the epoch 1994.0), new daily EOP and the corresponding station velocities, all based on the 1994 GPS data only.

Since it is not possible to submit a single solution for the EOP and SSC, the solution and the corresponding variance-covariance matrix were divided into an EOP part with standard deviations (EOP(EMR) 95 P 02) and the station positions and velocities (SSC(EMR) 95 P 02), which includes a complete variance-covariance matrix. For this submission we have applied small shifts and rotations to make the EOP, SSC and SSV solutions consistent with the 13 station ITRF93 SSC and SSV. The ITRF93 station velocities of the 13 stations were then highly constrained (at 0.01 times the ITRF93 SSV sigmas) to provide the reference for the time series of EOP and SSC as well as for the remaining station velocity solutions.

The EOP(EMR) 95 P 02 solution is reported in the IGS EOP format; the SSC(EMR) 95 P 02 solution uses parts of the proposed SINEX (Software INdependent EXchange) format, and includes complete information on a priori values, the antenna height offsets used, etc. More information on this batch reprocessing at NRCan is provided in Ferland *et al.* (1995).

References

Ferland, R., Kouba, J., Tetreault, P., Popelar J., and Dragert, H. 1995: Variation in EOP and station Coordinates Solution for Canadian Active Control System (CACS), A paper to be presented at the XXI General Assembly of IUGG, July 2-14, Boulder, Colo. (in prep.)

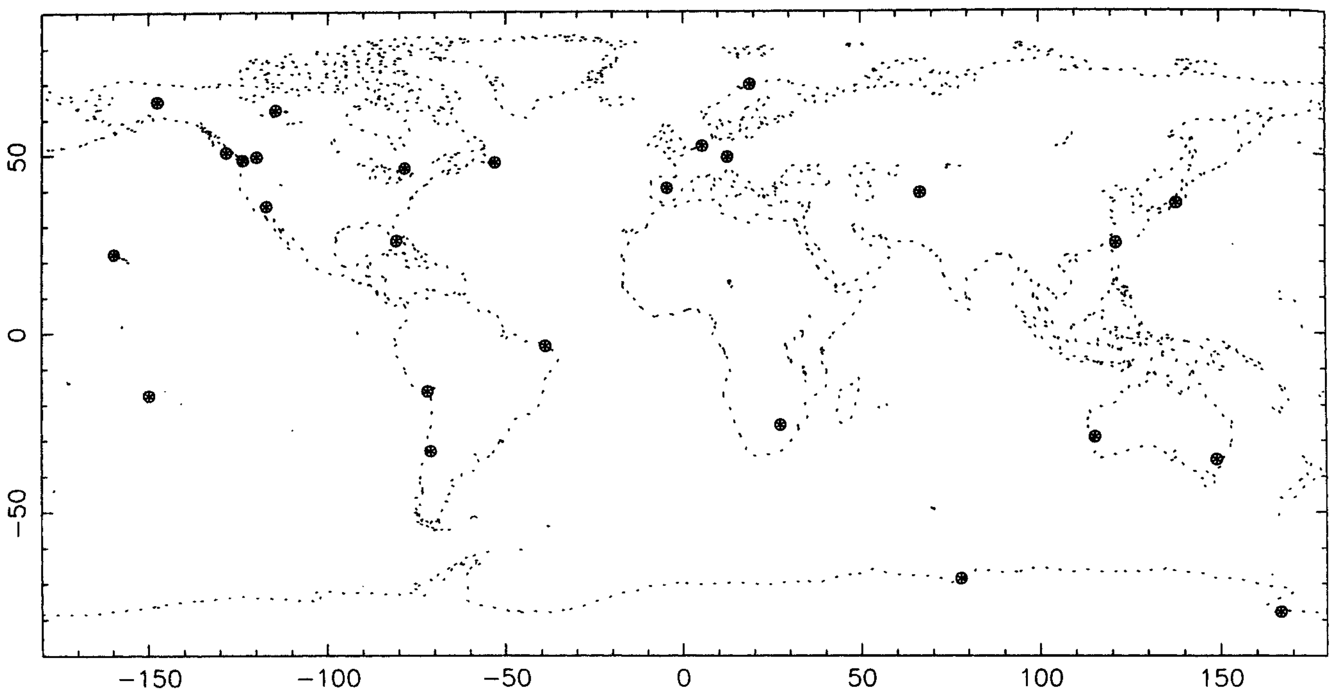
McCarthy, D.D. (ed), 1992: IERS Standards (1992), *IERS Technical Note 13,* Observatoire de Paris, Paris.

Pagiatakis, S.D., 1982: Ocean loading, body tides and polar motion effects on very long baseline interferometry, UNB Technical Rep. No. 2, Dept. of Surv. Engineering, Univ. of New Brunswick, Fredericton, N.B..

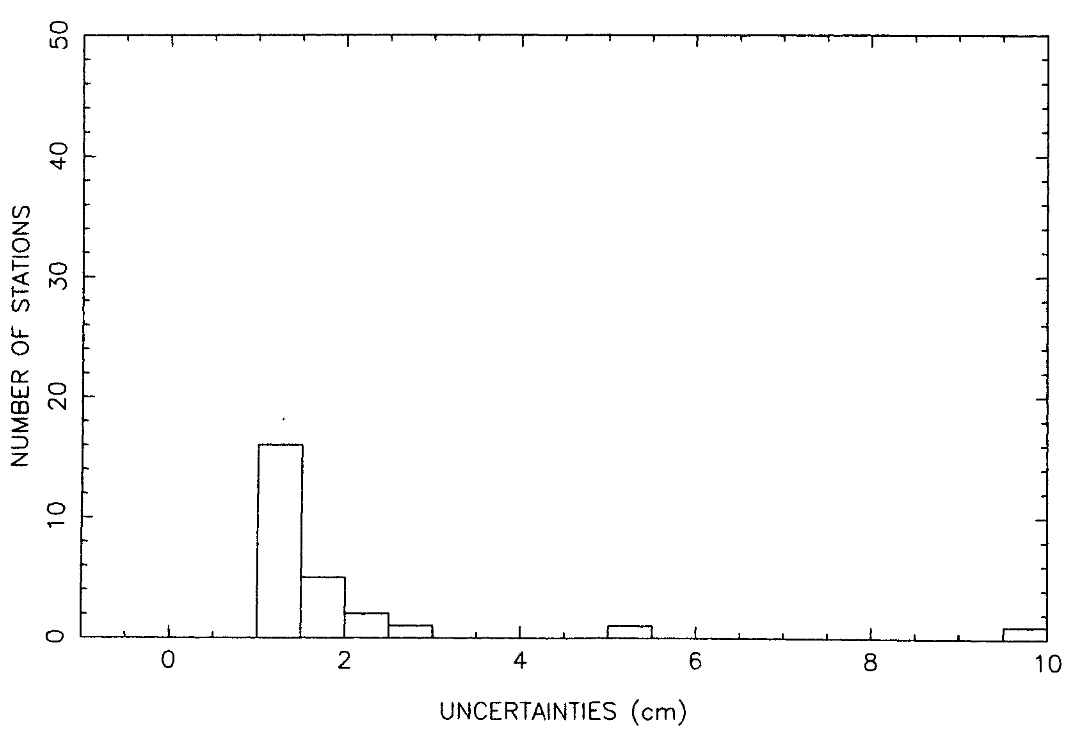
Tetreault, P., Kouba, J., Ferland, R., Popelar, J. 1995: NRCan (EMR) Analysis Report, 1994 IGS Annual Report (in prep.)

Technical description of solution EMR 95 P 02

1 - Technique:	GPS
2 - Analysis Center:	NRCan (Formerly EMR)
3 - Software used:	GIPSY II/ OASIS
4 - Data span:	Jan. 02-Dec. 31, 1994
5 - Celestial Reference Frame:	None
a - Nature:	25-26 GPS satellites
b - Definition of the orientation:	UT1-UTC (Bull. A) on Jan 2, 1994; 13 ITRF93 station velocities
6 - Terrestrial Reference Frame:	SSC(EMR) 95 P 02
a - Relativity scale:	LE
b - Velocity of light:	299 792 458 m/s
c - Geogravitational constant:	3.986004415 10^{14} m^3/s^2
d - Permanent tidal correction:	Yes
e - Definition of origin:	C10=0, C11=0, S11=0 (a coordinate shift, consistent with the 13 ITRF93 stations applied)
f - Definition of orientation:	ITRF93 (the 13 station coordinates)
g - Reference epoch:	1994.0
h - Tectonic plate model:	13 station ITRF93 coord. velocities
i - Constraint for time evolution:	13 station ITRF93 coord. velocities fixed (to ITRF93 SSV sigmas times 0.01)
7 - Earth orientation:	EOP(EMR) 95 P 02
a - A priori nutation model:	IAU (1980)
b - Short-period tidal variations in x, y, UT1:	No daily and sub-daily tidal variations applied
8 - Estimated Parameters:	
a - Celestial Frame:	Satellite states, X, Y, Z and Xdot, Ydot, Zdot (a priori sigmas: 1 km/0.005m/s or about 0.2m/sqrt (day); 0.1mm/s/sqrt (day))
b - Terrestrial Frame:	Station X0, Y0, Z0, Xdot, Ydot, Zdot (a priori sigmas: 10m for X0,Y0,Z0; the 13 station ITRF93 vel. sigmas times 0.01)
c - Earth Orientation:	x,y, UT1-UTC, LOD (since MJD 49515) (a priori sigmas: equivalent to 3m in x,y and UT1-UTC; 86 s/day for LOD)
d - Others:	Satellite and station clocks (a priori sigmas: 1ms and 1s resp.) Tropo Z. Delay (a constant and random walk with a priori sigmas: 0.2m and 0.01m/sqrt(h)) Sol. radiation press.: Gx, Gz and Gy (a priori sigmas: 10% for Gx, Gz and 0.5 10^{-9} m/s^2 for Gy) Initial phase ambiguities (a priori sigmas: 300 000 km)



Distribution of the 26 sites of the terrestrial frame SSC(EMR) 95 P 02.



Distribution of the uncertainties (quadratic mean of $\sigma_x, \sigma_y, \sigma_z$) for the 26 stations of the terrestrial frame SSC(EMR) 95 P 02.

EOP(EMR) 95 P 02 From Jan 1994 to Dec 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
1994	362	0.07	362	0.07	362	0.39

ANNUAL REPORT FROM THE ESOC IGS ANALYSIS CENTRE TO THE IERS FOR 1994

ESOC 94 P 01, 95 P 01

T. J. Martin Mur, J. M. Dow, J. Feltens (1), C. Garcia Martinez (2)
ESA / European Space Operations Centre (ESOC)
(1) mbp at ESOC, (2) GMV at ESOC

The ESOC contribution to the IERS for 1994 consists of a daily Earth Orientation Parameter solution, EOP(ESOC) 94 P 01, and a GPS station coordinate solution, SSC(ESOC) 95 P 01. The EOP solution has been obtained with the daily processing of GPS data for the IGS and the station coordinate solution has been obtained from 274 arcs of GPS observation equations from 1994.

Changes in 1994 in the EOP(ESOC) 94 P 01 series

For 1994 the terrestrial reference frame has been defined by fixing a set of 13 ground stations to the values given by the IERS and by using the ITRF92 velocity field. A continuous UT1R-TAI series is also provided. It has been obtained by the integration of the LODR solution.

Description of the GPS station coordinate solution SSC(ESOC) 95 P 01

Sites included
The stations that were included in the analysis were those stations that the ESOC/IGS Analysis Centre used for its 1994 daily IGS processing. They included all the 13 stations that are kept fixed in daily analysis, all the ESA receivers and additional receivers to obtain an evenly distributed tracking of the GPS satellites. All these stations are equipped with Rogue, MiniRogue, or TurboRogue precise geodetic GPS receivers connected to stable atomic frequency standards.

Arcs included
The periods of data used are 274 arcs of 1994. Observation equations were produced for the complete year, but other arcs are not used due to data or modelling problems. All GPS satellites were used, except those doing manoeuvres during each particular arc. For most of the stations we have used data from the whole year. The exceptions are KERG, KIT3, MATE and VILL, that were introduced in the daily ESOC analysis only for the last part of the year.

Initial station coordinates
Initial station coordinates were obtained from the ITRF93 station coordinate solution. Station positions were calculated at the different epochs using the velocities of the ITRF93. To obtain the velocities of those stations not included in the ITRF93 the NNR-NUVEL1 velocity field was used. Occupancies and antenna heights were obtained from the file localtie.tab maintained by the IGS Central Bureau.

Departures from IERS (1992) Standards

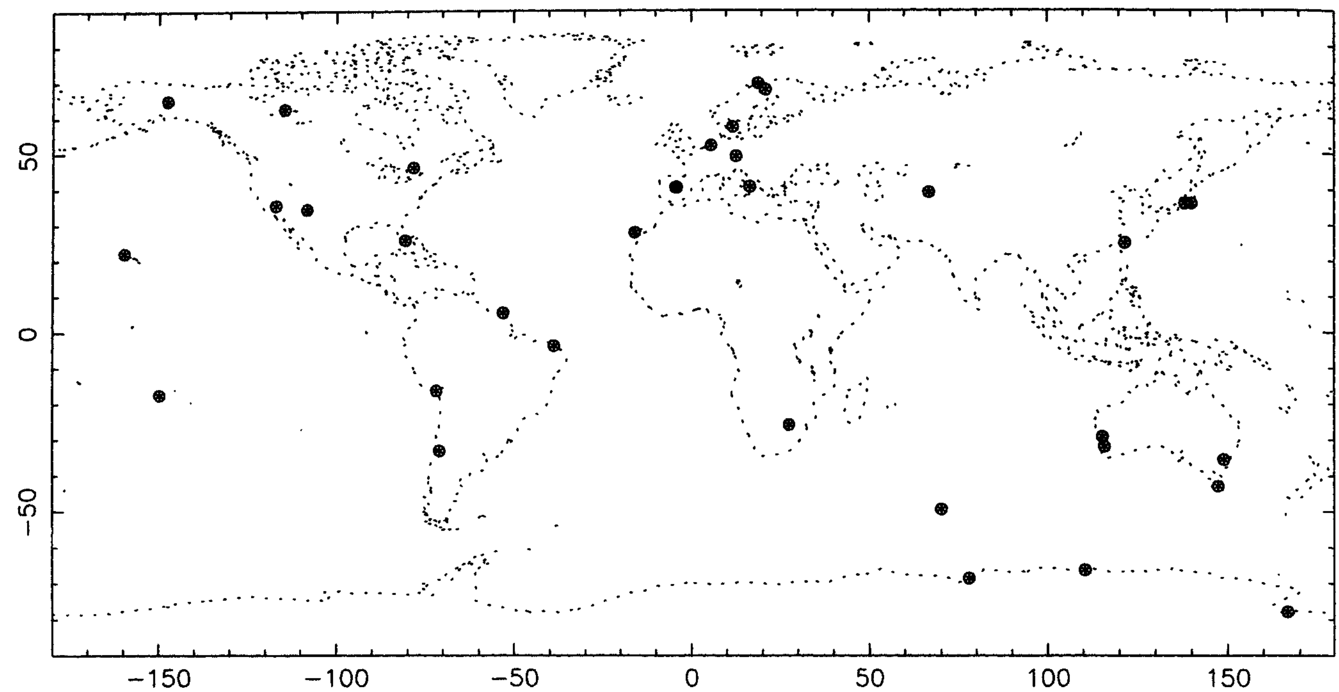
Relativistic corrections to the acceleration and to the propagation not applied. Ocean loading site displacement not applied.

Technical description of solution EOP(ESOC) 94 P 01

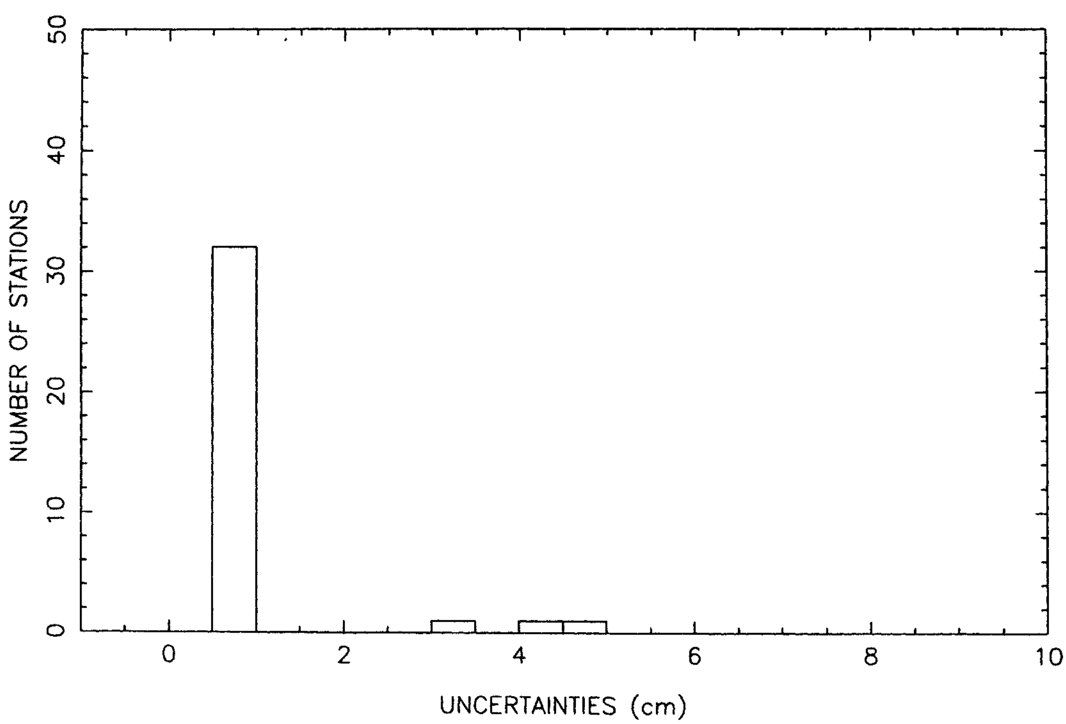
1 - Technique:	GPS
2 - Analysis Center:	ESA/European Space Operations Centre (ESOC)
3 - Software used:	GPSOBS/BAHN-V5
4 - Data span:	Dec 93 - Dec 94
5 - Celestial Reference Frame:	Mean Geocentric Equatorial System of 2000.0
a - Nature:	Dynamical
b - Definition of the orientation:	Using the IERS conventional models for precession and nutation, including celestial pole offsets.
6 - Terrestrial Reference Frame:	SSC(IERS) 93 C 04
a - Relativity Scale:	LE
b - Velocity of light:	299 792 458 m/s
c - Geogravitational constant:	3.986004415 10^{14} m^3/s^2
d - Permanent tidal correction:	No
e - Definition of origin:	Geocentre through C10=0, C11=0, S11=0.
f - Definition of orientation:	By fixing the coordinates of 13 fiducial stations to the SSC(IERS) 93 C 04 values.
g - Reference epoch:	1993.0
h - Tectonic plate model:	ITRF92 + NNR-NUVEL1
i - Constraint for time evolution:	by fixing 13 station coordinates and velocities to the ITRF92 solution.
7 - Earth Orientation:	EOP(ESOC) 94 P 01
a - A priori nutation model:	IAU(1980), corrected for celestial pole offsets from IERS Bulletin B.
b - Short-period tidal variations in x, y, UT1:	x, y and UT1R rate estimated as constants for 24 hours intervals. Short period UT1 variations modelled using Yoder (1981) model.
8 - Estimated parameters:	
a - Celestial Frame:	None
b - Terrestrial Frame:	Coordinates for stations that are not fixed.
c - Earth Orientation:	One set of pole coordinates xp, yp and LODR per day.
d - Others:	Satellite parameters per spacecraft: - one orbital state at start epoch. - one scaling factor for radiation pressure ROCK4 T10 or T20 model. - one Y-bias acceleration. Station related parameters per ground station: - every 6 hours an atmospheric zenith delay and a shape parameter. - clock biases and clock drifts as needed. - double-differenced phase ambiguities as real-valued parameters.

Technical description of solution SSC(ESOC) 95 P 01

1 - Technique:	GPS
2 - Analysis Center:	ESA / European Space Operations Centre (ESOC)
3 - Software used:	GPSOBS/BAHN-V5/MULTIARC
4 - Data span:	Jan 94 - Dec 94
5 - Celestial Reference Frame:	Mean Geocentric Equatorial System of 2000.0
a - Nature:	Dynamical
b - Definition of the orientation:	Using the IERS conventional models for precession and nutation, including celestial pole offsets.
6 - Terrestrial Reference Frame:	SSC(ESOC) 95 P 01
a - Relativity Scale:	LE
b - Velocity of light:	299 792 458 m/s
c - Geogravitational constant:	3.986004415 10^{14} m^{3}s^2
d - Permanent tidal correction :	No
e - Definition of origin:	Geocentre through C10=0, C11=0, S11=0.
f - Definition of the orientation:	By using the IERS Bulletin B Earth rotation parameters and applying a loose constraint to station positions and horizontal velocities.
g - Reference epoch:	1994.0
h - Tectonic plate model:	For those stations for which the velocity is not estimated NNR-NUVEL1 is used.
i - Constraint for time evolution:	By using the IERS Bulletin B Earth rotation parameters and applying a loose constraint to station horizontal velocities.
7 - Earth Orientation:	IERS Bulletin B
a - A priori nutation model:	IAU(1980), corrected for celestial pole offsets from IERS Bulletin B.
b - Short-period tidal variations in x, y, UT1:	linear x, y and UT1R in 24 hour intervals. Short period UT1 variations modelled using Yoder (1981) model.
8 - Estimated parameters:	
a - Celestial Frame:	None
b - Terrestrial Frame:	Coordinates of 35 IGS stations. Horizontal velocities of 30 IGS sites.
c - Earth Orientation:	None.
d - Others:	None.



Distribution of the 34 sites of the terrestrial frame SSC(ESOC) 95 P 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 35 stations of the terrestrial frame SSC(ESOC) 95 P 01.

EOP(ESOC) 94 P 01 From Dec 1993 to Dec 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
1993	6	0.08	6	0.08	6	0.15
1994	365	0.10	365	0.10	365	0.15

EARTH ROTATION PARAMETERS, STATION COORDINATES AND VELOCITIES FROM GPS DATA

GFZ 95 P 02, 03

G. Gendt, G. Dick, Ch. Reigber, W. Sommerfeld, Th. Nischan
GeoForschungsZentrum (GFZ) Potsdam

A global Set of Station Coordinates (SSC(GFZ) 95 P 02) and Earth Rotation Parameters (EOP(GFZ) 95 P 02) are computed from the 1993/1994 global GPS data set using the GFZ analysis software package EPOS.P.V2. Additionally results from simultaneous adjustment of station coordinates and velocities are presented (SSC(GFZ) 95 P 03).

Data

The initial data acquired at the GFZ-IGS Center are the 30 sec RINEX data from the IGS stations collected at the global data centers CDDIS and IGN.

For the analysis itself undifferenced ionospheric free phases with a sampling rate of 6 minutes were used. RINEX data sessions of 32 hours in length were formed, which overlap by 8 hours from day to day. P-code data were entered into the analysis to preset the ambiguities. The identified ambiguities were constrained to the expected P-code accuracy. Consecutive data segments of 32 hours were formed to carry out the solutions including a quality assessment in overlapping orbital segments. The number of sites used varies from 23 in 1993 to 42 in 1994.

Analysis

The solutions were obtained by using GFZ EPOS.P.V2 Software package, which is adapted to the IERS Standards with the few exceptions indicated below. The adjusted parameter set results from a HELMERT blocking. For each parameter the resolution time can be chosen freely. The orbital elements are adjusted independently from day to day. To get a stable reference for the pole parameter determination a set of 12 stations was fixed for this purpose. The nominal values for these sites vary within the two years (in 1994 it was the ITRF92 system). The whole series is homogenized to compensate for jumps originating from these changes.

The Earth Rotation Parameters (pole coordinates and length of day) were adjusted as daily values (first 24 hours of each session). These values are practically independent from day to day. The accuracy is 0.25 mas for the pole position (difference to the mean of all IGS series) and 0.06 ms for LODR (compared to Bulletin B).

For the determination of station coordinates fiducial-free normal equations were archived. These normal equations were combined into a two-year system to derive the global station position solution SSC(GFZ) 95 P 02. To define the orientation three horizontal site parameters were fixed. The site velocities were fixed to the ITRF93 values (SSC(IERS) 94 C 01). A small net rotation to ITRF93 was eliminated by a 7-parameter similarity transformation.

A second solution for the reference frame, SSC(GFZ) 95 P 03, was determined where the site positions and the horizontal site velocities were adjusted simultaneously. Velocities for sites with less than 6 months of data were fixed.

The internal consistency of the determined reference frame is in the sub-cm level and reaches the mm level for the denser parts of the network . Results from a Helmert transformation are given in the table below (units in mm).

data set A	data set B	Stations compared	#sta	with ITRF93 velocities North	East	Up	with GFZ velocities North	East	Up
P01	ITRF93	global	24	4.2	4.0	9.1			
1993	1994	global	24	4.2	5.4	4.6	2.3	2.8	5.0
1993	1994	NoAmerika&Europe	16	2.7	2.3	3.3	0.9	0.9	3.7
1993	1994	Europe	8	1.4	1.2	2.3	0.6	0.5	2.5

The geocenter differs between the yearly solutions in the range of a few cm.

References

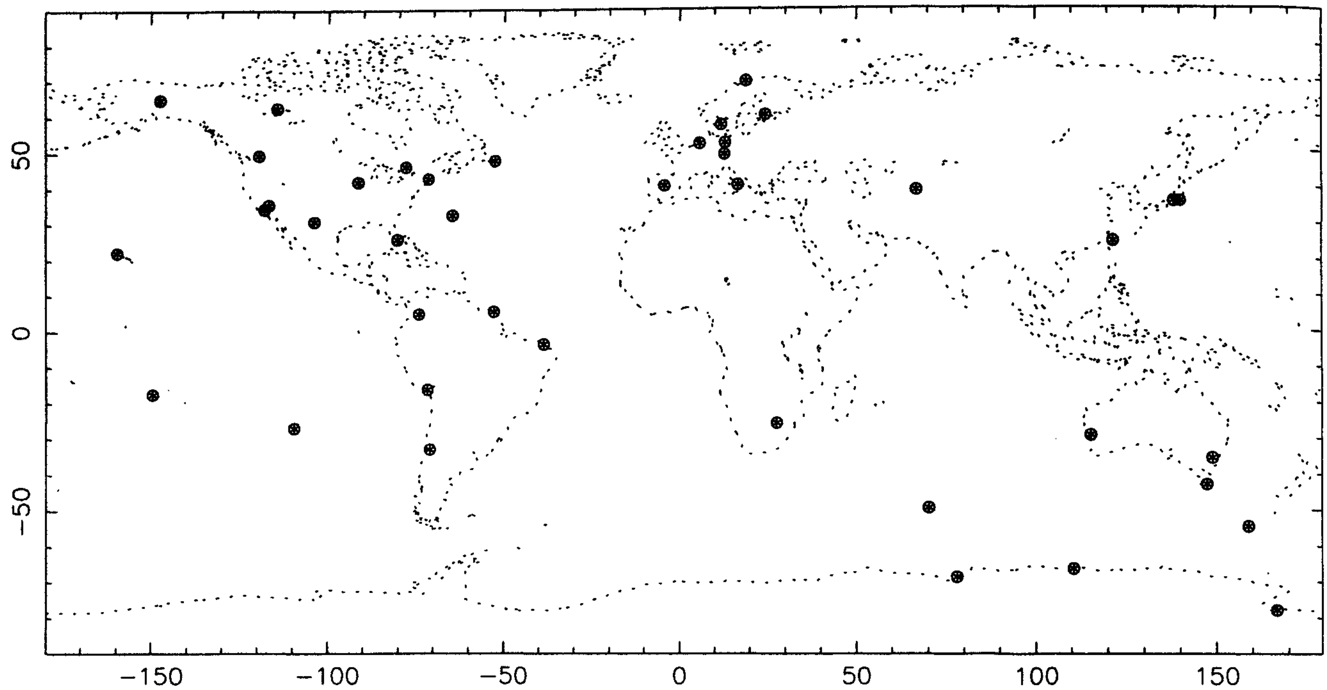
Reigber, Ch., Dick, G., Galas, R., Gendt, G., Montag, H., Zhu, S.Y., 1993: Investigation of high resolution Earth rotation parameters as determined from SLR and GPS data at Potsdam, Paper presented at IAG General Meeting, Beijing, August 8-13,1993

Gendt, G., Dick, G., Mai, W., Reigber, Ch., Nischan, Th., 1994: Earth Rotation Parameters and Station Coordinates from GPS Data, *IERS Technical Note 17,* P. Charlot (ed.), Observatoire de Paris, Paris, pp. P-37 - P-41.

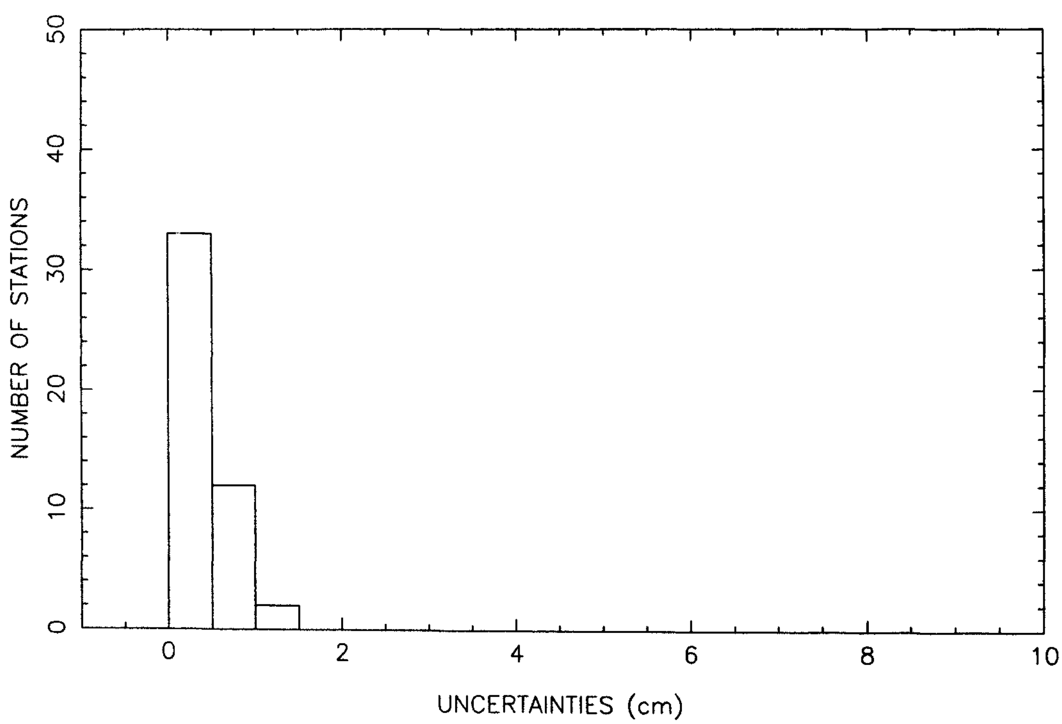
Gendt, G., Dick, G., Reigber, Ch., 1994: Plate Motions on a Global Scale Derived from GPS Data of the IGS Core Network, Paper presented at AGU Fall Meeting, Dec. 5-9, 1994 San Francisco, Abstract in EOS, Nov.1, 1994, p. 162 (G21A-5).

Technical description for solutions GFZ 95 P 02 and 95 P 03

1 - Technique :	GPS
2 - Analysis Center :	GFZ
3 - Software used :	EPOS.P.V2
4 - Data span:	Jan 93 - Dec 94
5 - Celestial reference frame :	
a - Nature :	dynamical
b - Definition of orientation :	aligned to UT1 form IERS Bulletin B
6 - Terrestrial Reference Frame :	SSC(GFZ) 95 P 02 and SSC(GFZ) 95 P 03
a - Relativity Scale :	none
b - Velocity of light :	299 792 458 m/s
c - Geogravitational constant:	3.986004418 10^{14} m^3/s^2
d - Permanent tidal correction:	yes (permanent tide not in listed coordinates)
e - Definition of origin :	C(1,0)=C(1,1)=S(1,1)=0
f - Definition of orientation :	longitude, latitude of ALGO fixed, latitude of WETT fixed, plus alignment to ITRF93 SSC(IERS) 94 C 01 by similarity transformation
g - Reference epoch :	1994.0 (MJD 49352)
h - Tectonic plate model :	ITRF93 Velocities
i - Constraint of time evolution:	a) SSC(GFZ) 95 P 02: fixed to ITRF93 Velocities b) SSC(GFZ) 95 P 03: vel_longitude, vel_latitude of ALGO, fixed vel_latitude of WETT fixed, plus alignment to ITRF93 Velocities by similarity transformation
7 - Earth Orientation :	EOP(GFZ) 95 P 02 (for SSC(GFZ) 95 P 02)
a - A priori nutation model :	IAU(1980)
b - Short-period tidal variations in x, y, UT1 :	UT1 zonal tides with periods < 35 days
8 - Estimated parameters :	
a - Celestial Frame :	none
b - Terrestrial Frame :	longitude, latitude, radius (vel_longitude, vel_lati for SSC(GFZ) 95 P 03)
c - Earth Orientation :	daily x, y and LODR
d - Others :	Orbit - 6 orbital parameters for 32-hour intervals - Reflectance coefficient, y-bias for 32 h - Tropospheric zenith path delay for 4-hour intervals - Ambiguities - Epoch time parameters



Distribution of the 41 sites of the terrestrial frame SSC(GFZ) 95 P 02.



Distribution of the uncertainties (quadratic mean of $\sigma_x, \sigma_y, \sigma_z$) for the 47 stations of the terrestrial frame SSC(GFZ) 95 P 02.

EOP(GFZ) 95 P 02 From Jan 1993 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
1993	360	0.04	360	0.03	360	0.40
1994	365	0.03	365	0.03	365	0.40
1995	3	0.03	3	0.03	3	0.40

COORDINATES, VELOCITIES, AND EOP FROM THE JET PROPULSION LABORATORY USING GPS

JPL 95 P 02

M. Heflin, M. Watkins, D. Jefferson, F. Webb, and J. Zumberge
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA

Velocities and positions have been computed for 46 separate GPS monuments. The 16348 station days of data span four years from January 22, 1991 through January, 27 1995. Daily estimation was carried out by the Jet Propulsion Laboratory's geodetic analysis team. Past and present participants include Geoffrey Blewitt, Michael Heflin, David Jefferson, Yvonne Vigue, Michael Watkins, Frank Webb, and James Zumberge. The analysis strategies generally adhered to IERS/IGS standards and are described by Zumberge and Jefferson (1992), Heflin *et al.* (1992, 1994), Blewitt *et al.* (1992), Vigue *et al.* (1994), and Bar-Sever *et al.* (1995). Mean daily repeatability for all sites was determined to be 6 mm, 8 mm, and 13 mm for latitude, longitude, and height respectively.

Antenna heights were corrected on each day by comparing the value used during analysis to the official value listed at the IGS central bureau. Next, the daily solutions were combined, using their full covariance matrices, to obtain position and velocity estimates for each site. Formal errors were scaled by 1.8 to make chi-squared per degree of freedom equal to one. Finally, the reference frame was defined by application of internal constraints and rotation into ITRF93. The geocenter and scale were left at their GPS derived values.

The updated site position and velocity solution was then backsubstituted into the full information matrices (when available) for the daily Earth orientation parameters and station positions. This yielded a consistent EOP series spanning the period from mid 1992 through early 1995. Significant outliers were edited relative to a light smoothing. Because of gaps in the series, length of day has not been integrated in to UT1, and hence only x and y pole are included in this report. The resulting series demonstrates internal precision on the order of 0.2 to 0.3 mas. A scaling of approximately 2.5 will make the formal errors reported for the EOP series consistent with the internal precision.

Acknowledgements

This research was partially carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. We thank the numerous institutions and individuals who operate the GPS constellation and global receiver network.

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Bar-Sever, Y., Anselmi, J., Bertiger, W., and Davis, E., 1995: Fixing the GPS Bad Attitude: Modeling GPS Satellite Yaw During Eclipse Seasons, *ION 1995 National Technical Meeting Proceedings.*

Blewitt, G., Heflin, M., Bertiger, W., Webb, F., Lindqwister, U., and Malla, R., 1992: Global Coordinates With Centimeter Accuracy In The International Terrestrial Reference Frame Using The Global Positioning System, *Geophys. Res. Lett.*, **19**, No. 9, 853-856.

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.

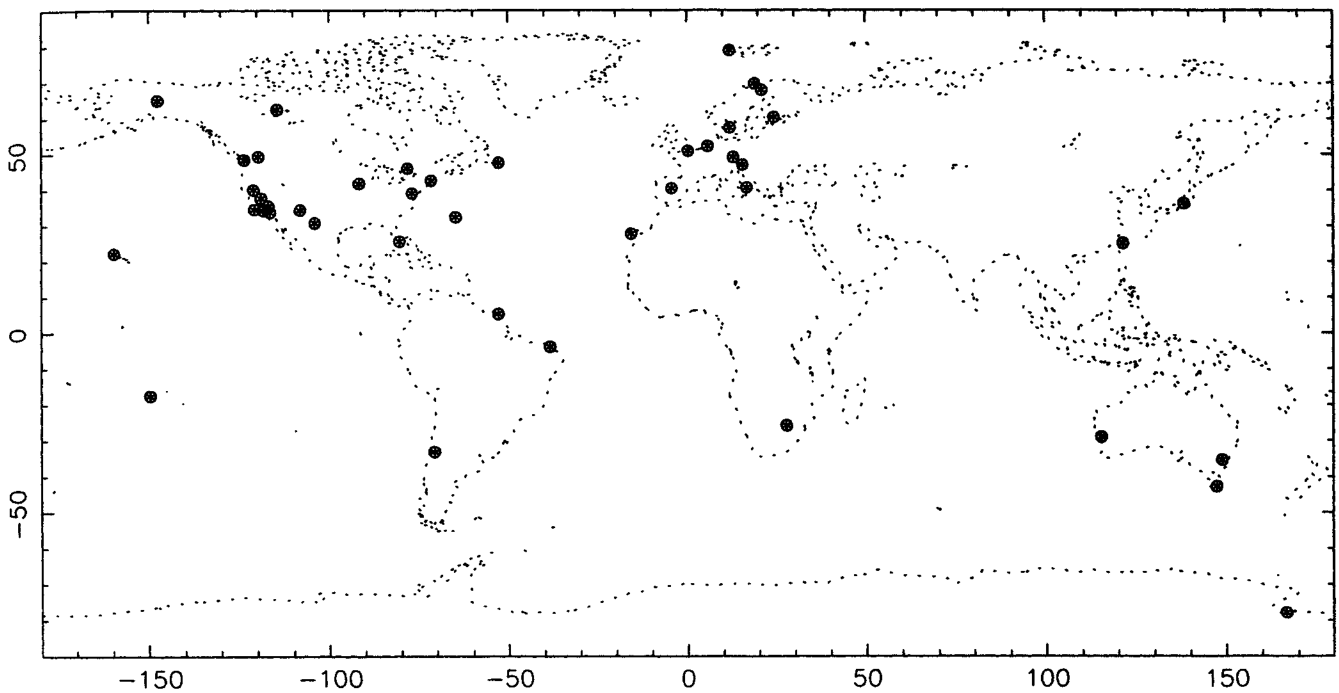
Heflin, M., Jefferson, D., Vigue, Y., Watkins, M., Webb, F., and Zumberge, J., 1993: GPS Time Series: January 22, 1991-April 1, 1994, IOM 335.4-94-008 (JPL internal document), Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

Vigue, Y., Lichten, S., Muellerschoen, R., Blewitt, G., and Heflin, M., 1994: Improved GPS Solar Radiation Pressure Modeling for Precise Orbit Determination, *Journal of Spacecraft and Rockets,* **31**, No. 5, 830-833.

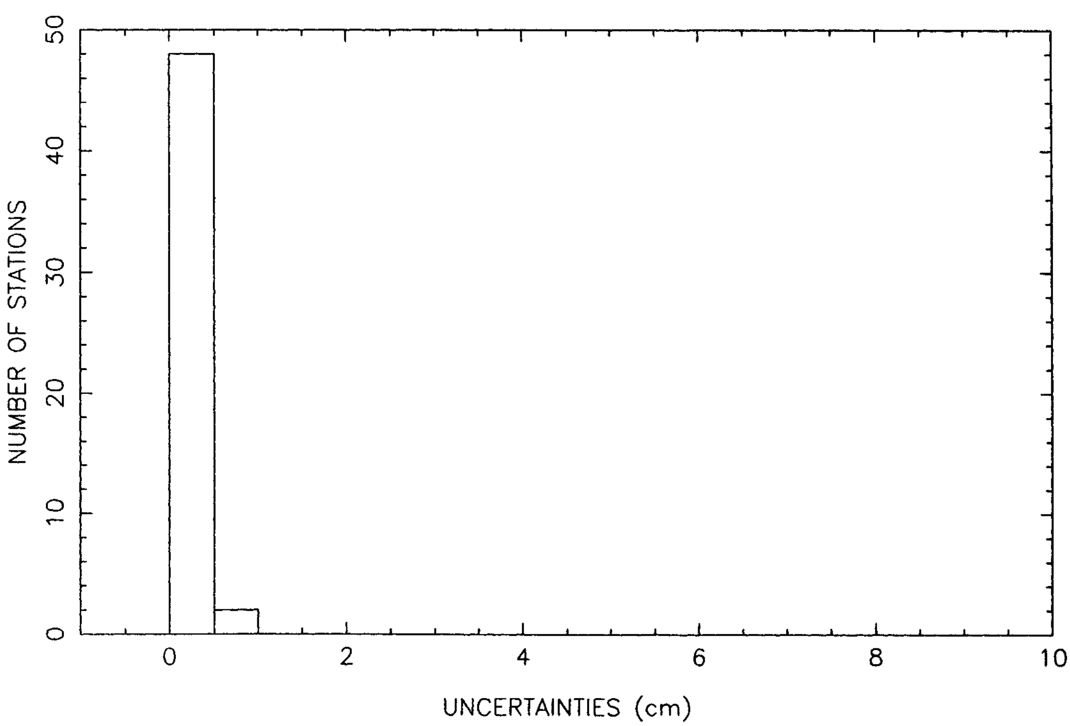
Zumberge, J., and Jefferson, D., 1992: An Analysts Guide to FLINN Reduction of GPS Data, IOM 335.4P92P013 (JPL internal document), Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

Technical description of solution JPL 95 P 02

1 - Technique:	GPS
2 - Analysis Center:	Jet Propulsion Laboratory, California Institute of Technology
3 - Software used:	GIPSY-OASIS II
4 - Data span:	January 22, 1991 - January 27, 1995 16348 station days
5 - Celestial Reference Frame:	not applicable
a - Nature:	Dynamical, GPS spacecraft
b - Definition of the orientation:	
6 - Terrestrial Reference Frame:	SSC(JPL) 95 P 02
a - Relativity scale:	Local Earth
b - Velocity of light:	C = 299792458 m/sec
c - Geogravitational constant:	GM0 = 3.986004415 10^{14} m^3 s^{-2}
d - Permanent tidal correction:	No
e - Definition of origin:	Defined by GPS s/c dynamics through C10=0,C11=0,S11=0
f - Definition of orientation:	No net rotation with respect to ITRF93
g - Reference epoch:	1993.0
h - Tectonic plate model:	None
i - Constraint for time evolution:	No net rotation rate with respect to ITRF93
7 - Earth orientation:	EOP(JPL) 95 P 02
a - A priori nutation model:	IAU(1980)
b - Short-period tidal variations in x, y, UT1:	Sub-daily tidal variations not subtracted from reported series, sub-daily tidal variations modelled beginning December 10, 1994
8 - Estimated Parameters:	
a - Celestial Frame:	Satellite initial conditions, yaw rate, and empirical accelerations
b - Terrestrial Frame:	X0, Y0, Z0, Xdot, Ydot, Zdot
c - Earth Orientation:	x, y (LOD estimated but not included in EOP(JPL) 95 P 02)
d - Others:	Satellite and site clocks adjusted each epoch, phase biases estimated as real valued parameters, tropospheric zenith delay adjusted stochastically at each site.



Distribution of the 43 sites of the terrestrial frame SSC(JPL) 95 P 02.



Distribution of the uncertainties (quadratic mean of $\sigma_x, \sigma_y, \sigma_z$) for the 50 stations of the terrestrial frame SSC(JPL) 95 P 02.

EOP(JPL) 95 P 02 From Jun 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	131	0.15	131	0.17
1993	340	0.11	340	0.12
1994	344	0.08	344	0.08
1995	27	0.09	27	0.09

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.

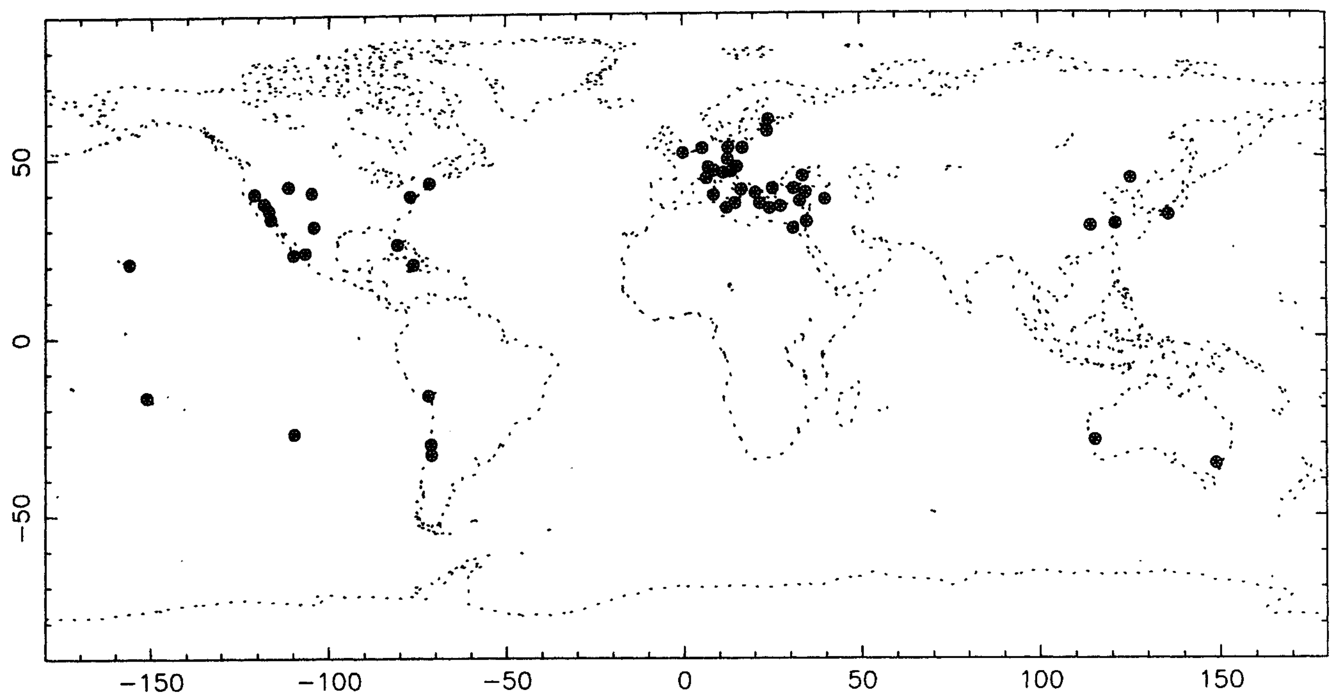
The latitude of Haleakala (7210) and the longitude and the latitude of Greenbelt (7105) are fixed at their ITRF91 values. The latitude and longitude rates of 20 sites are fixed at NNR-NUVEL1 velocities.

References

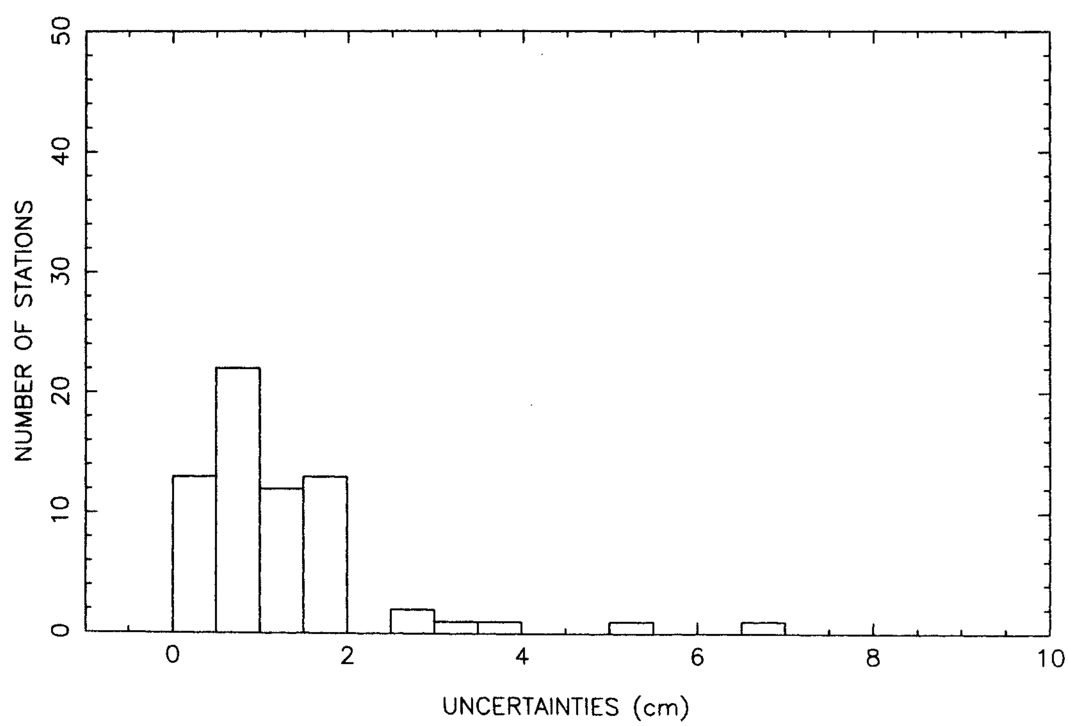
McCarthy, D.D. (ed.), 1992: IERS Standards (1992), *IERS Technical Note 13,* Observatoire de Paris, Paris.

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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Center for Space Research, University of Texas at Austin, Austin TX 78712
M. M. Watkins
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

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].

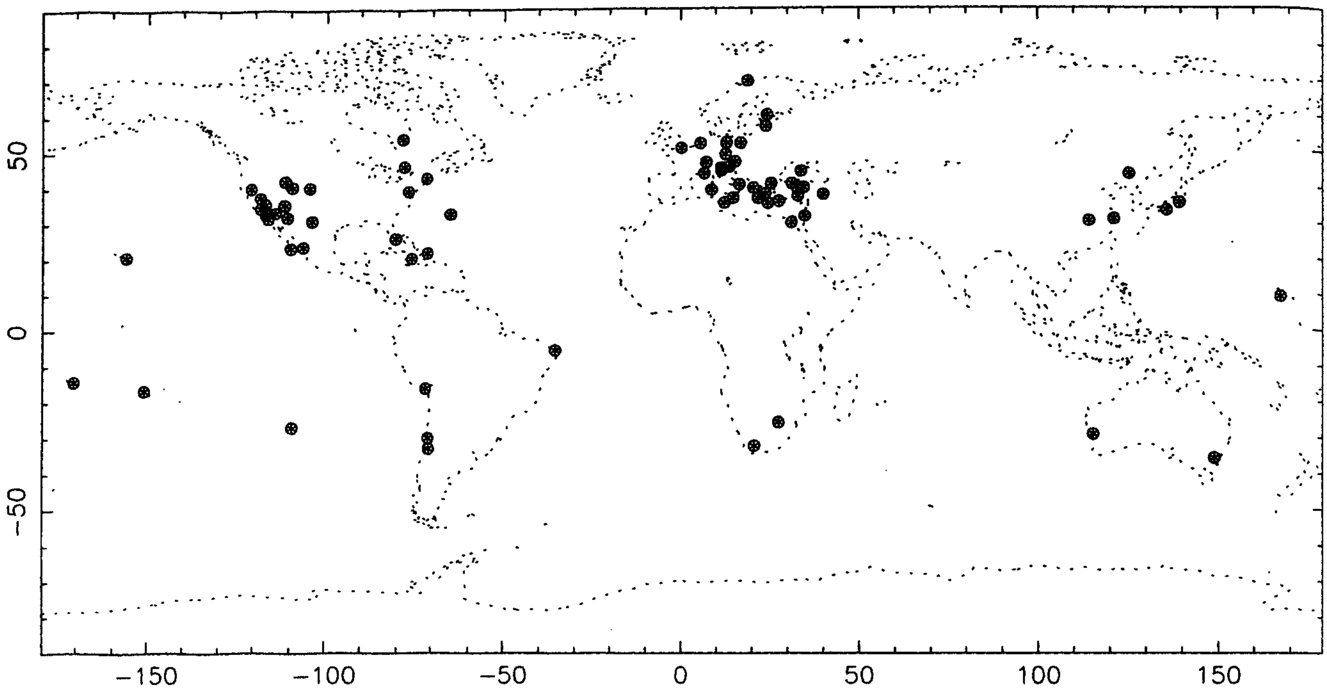
References

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.

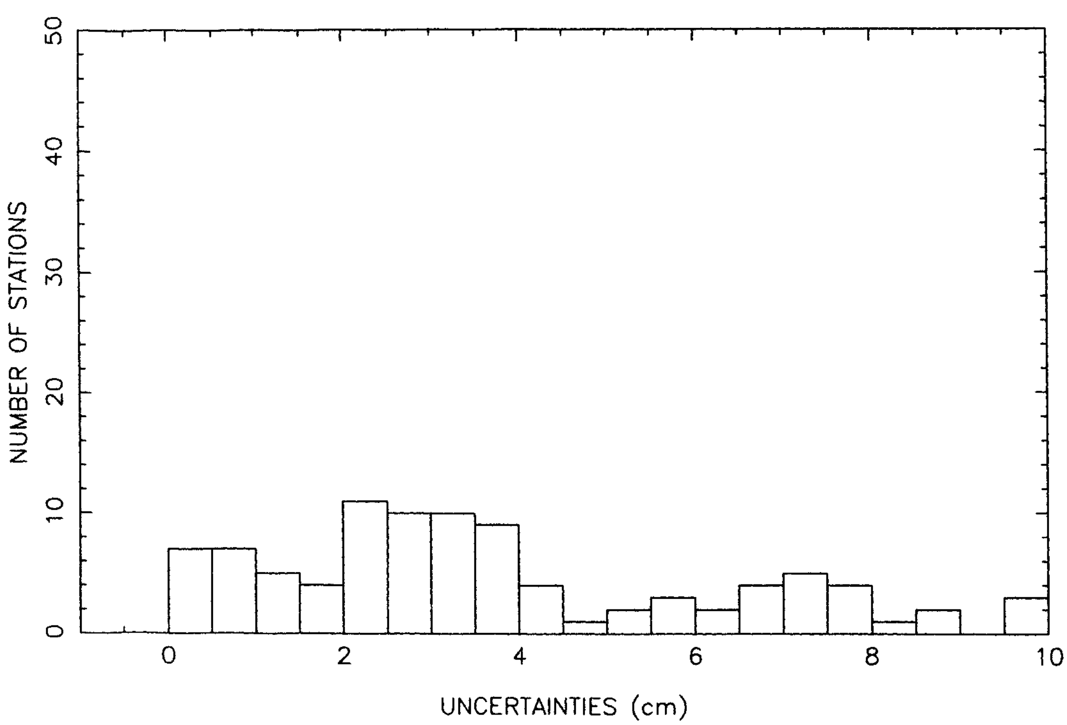
Heflin, M., Bertiger, W., Blewitt, G., Freedman, A., Hurst, K., Lichten, S., Lindqwister, U., Vigue, Y., Webb, F., Yunck, T., and Zumberge, J., 1992: Global Geodesy Using GPS Without Fiducial Sites, *Geophys. Res. Lett.,* **19,** No. 2, 131-134

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

R. Noomen[1], B.A.C. Ambrosius[1], K. Herzberger[2], D.C. Kuijper[1], H. Leenman[1], G.J. Mets[1], B. Overgaauw[1], T.A. Springer[1], K.F. Wakker[1]
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[2] Institut für Angewandte Geodaesie, Richard-Strauss-Allee 11, D-60598 Frankfurt am Main 70, Germany

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.

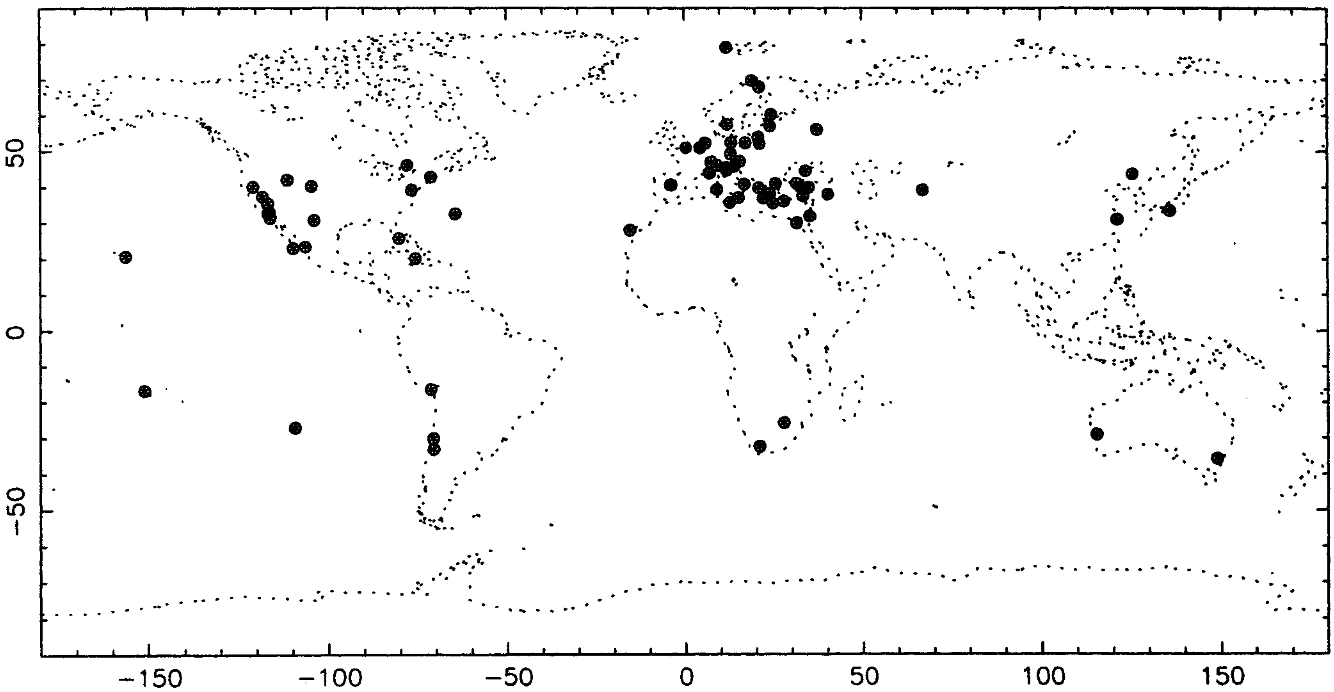
The model for the station positions and velocities was based on a series of independent network solutions, determined either from SLR or from GPS, and covering the periods mentioned above. In the computation of these individual network solutions, tectonic deformations were not modeled or estimated. This 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.

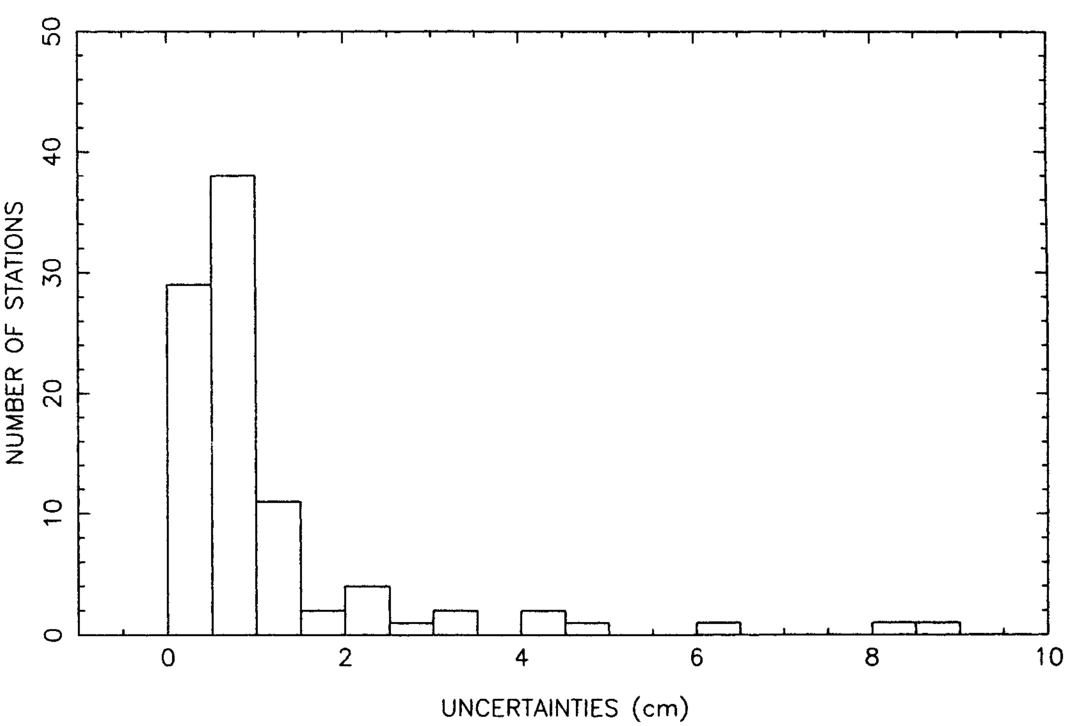
In the second step, the resulting model for instantaneous station positions was back-substituted into the previous step: the computations were repeated, but now with these station positions held fixed and the pole position and UT1 parameters estimated freely. Since the GPS networks analysed here are 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 $\sigma_x, \sigma_y, \sigma_z$) 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

V.N. Salyamov - Main Astronomical Observatory of Ukrainian Academy of Sciences, Dept. of Space Geodynamics, Kiev-22, Ukraine, 252022

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

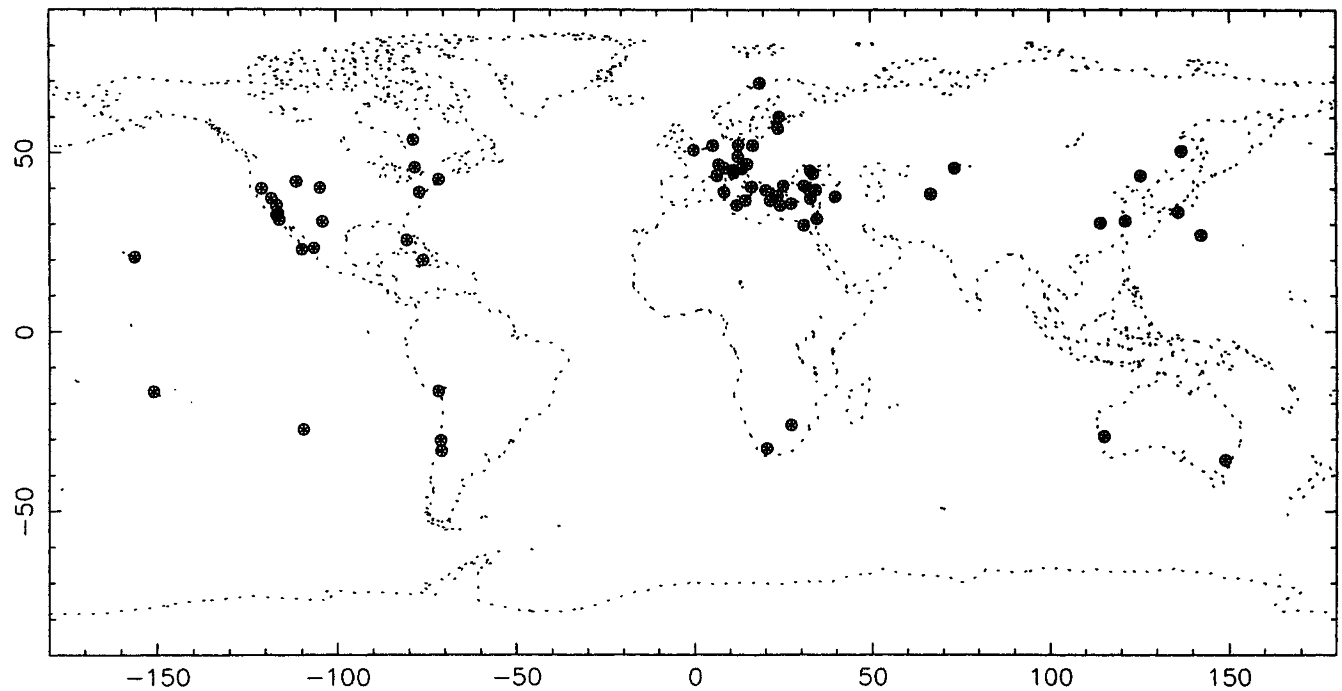
4 - Data span: Sep 1983 - Oct 1994 (MJD 45581 - 49656)

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

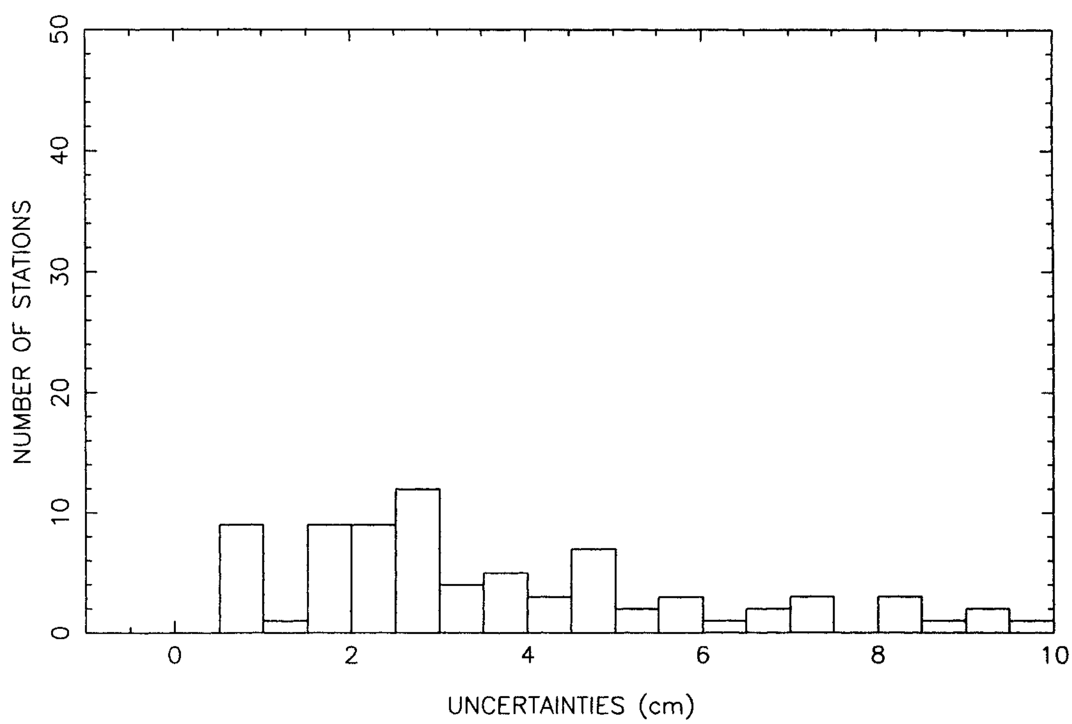
6 - Terrestrial Reference Frame: SSC(GAOUA) 95 L 02
- a - Relativity scale: LE
- b - Velocity of light: 299792458 m/s
- c - Geogravitational constant: $3.986004415 \; 10^{14} \; m^3/s^2$
- d - Permanent tidal correction: Yes
- e - Definition of origin: C10=C11=S11=0
- f - Definition of orientation: EOP 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 $\sigma_x, \sigma_y, \sigma_z$) 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

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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

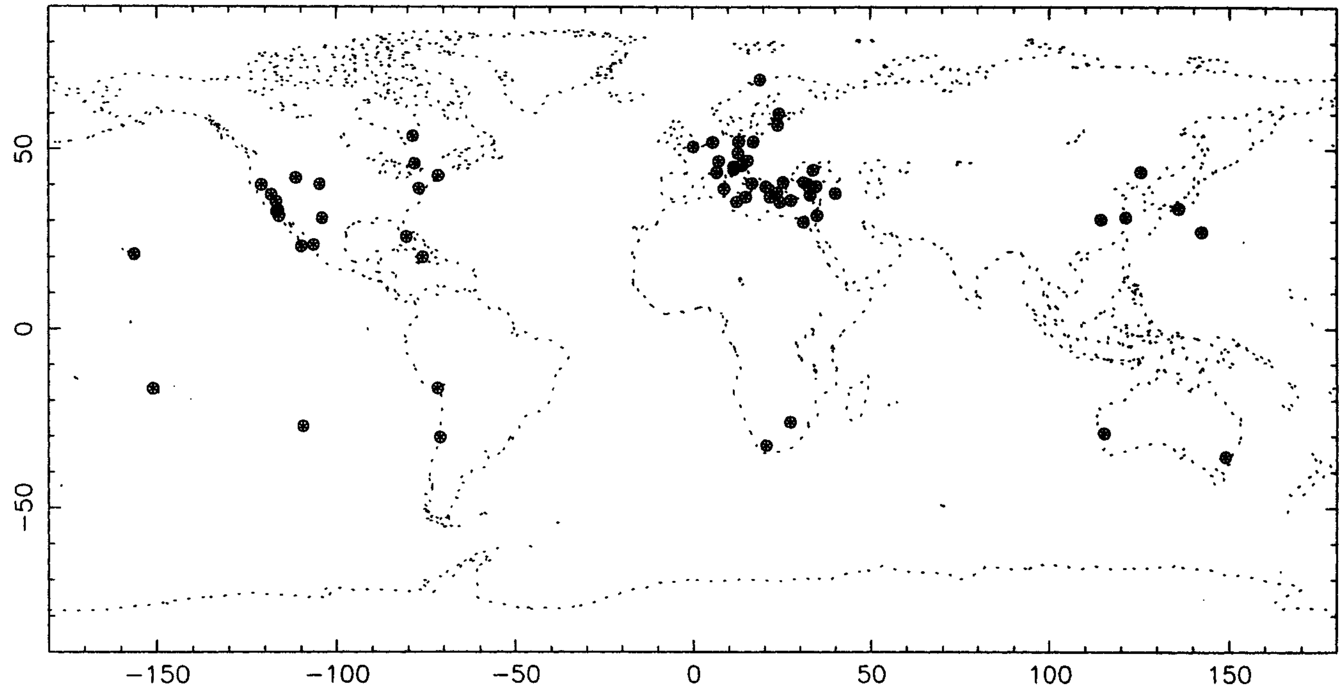
DeMets, C., Gordon, R.G., Argus, D.F., and Stein, S., 1990: Current plate motions, *Geophys. J. Int.,* **101**, 425-478.

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

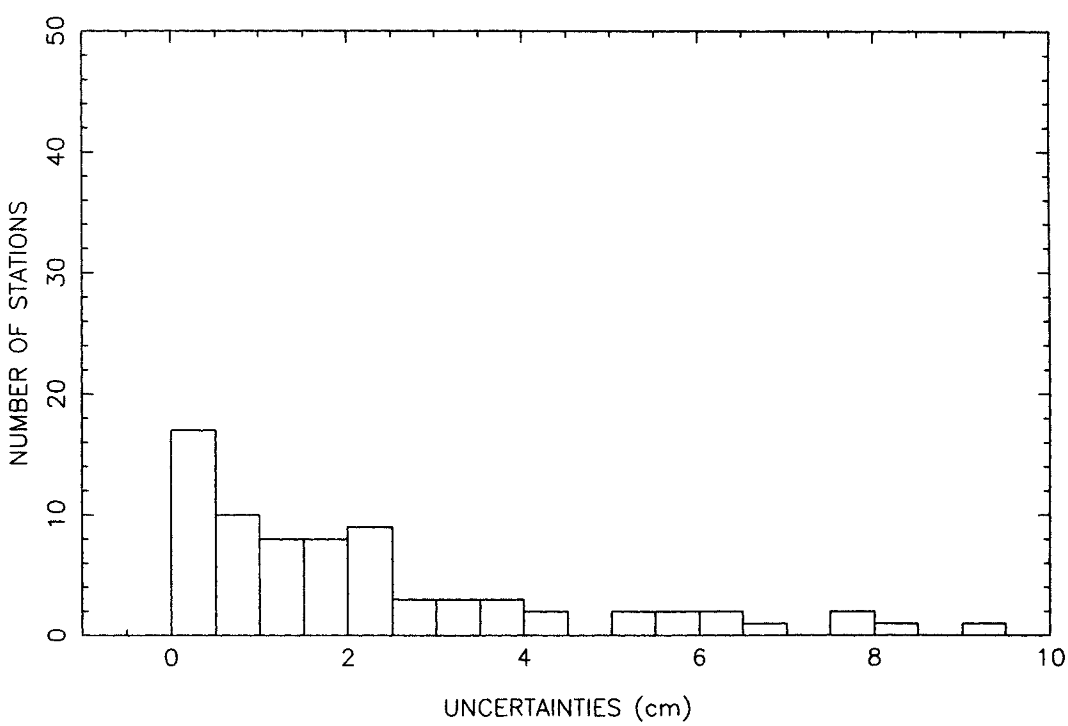
Montag, H., Reigber, Ch., Sommerfeld, W., Dick, G., 1994: Station coordinates and Earth rotation parameters based on Lageos laser ranging data, *IERS Technical Note 17,* P. Charlot, (ed.), Observatoire de Paris, Paris, L25-L30.

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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P.J. Dunn, S.M. Klosko, J.W. Robbins, M.H. Torrence and R.G. Williamson
Hughes STX Corp., Greenbelt, MD 20770

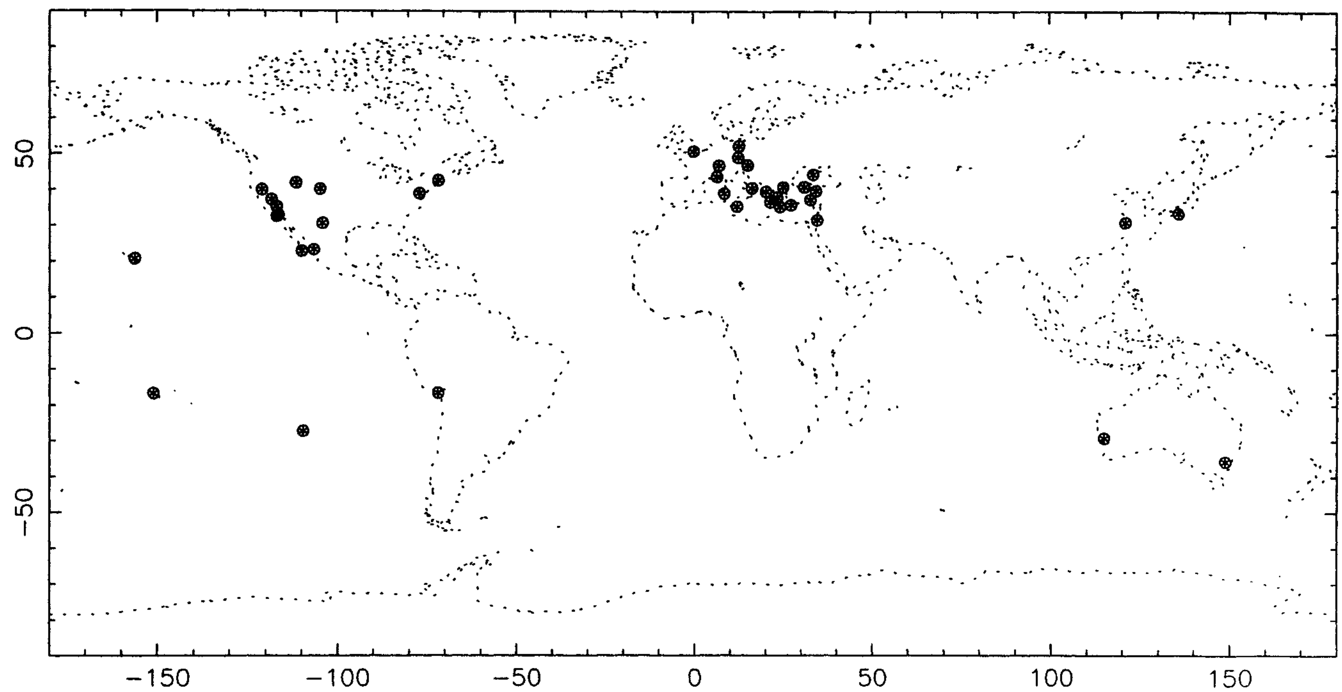
E.C. Pavlis
U. of Md. Dept. of Astronomy and NASA/GSFC, Greenbelt MD 20771

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.

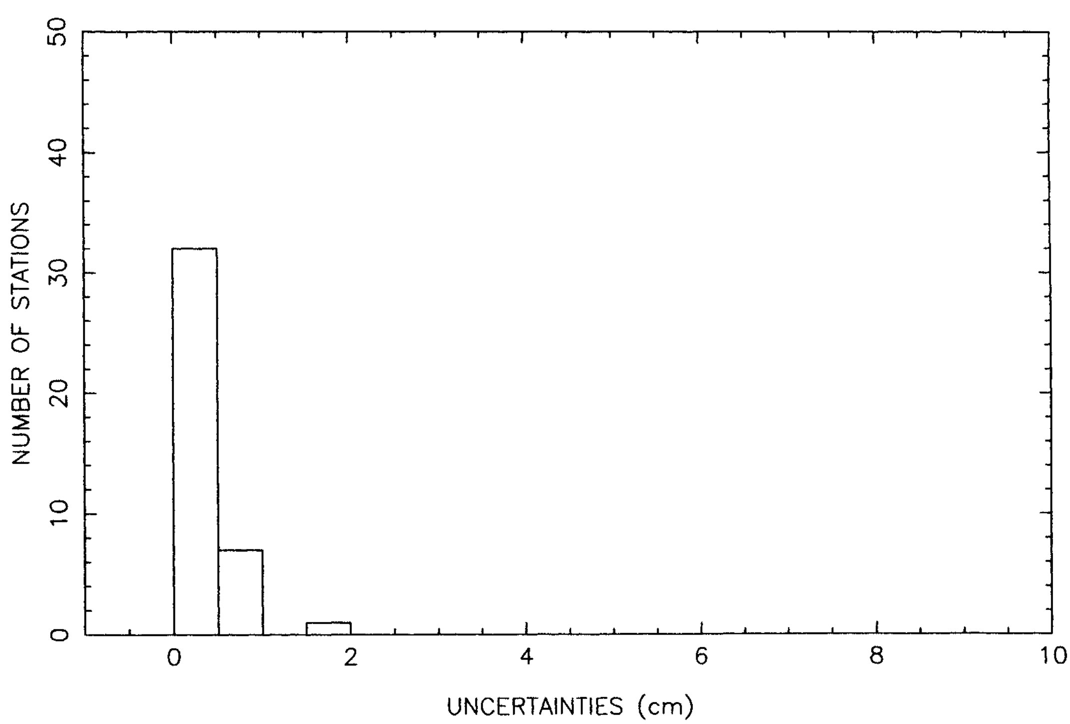
The EOP series from this solution was edited by means of a "Vondrak"-smoothing procedure using an epsilon value of 100. The resulting series are identical to the "raw" series except for the few cases where some spurious values were substituted with values interpolated from adjacent data points. This 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 $\sigma_x, \sigma_y, \sigma_z$) 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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Institute of Astronomy, Russian Academy of Sciences, 109017, Moscow, Russia

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.

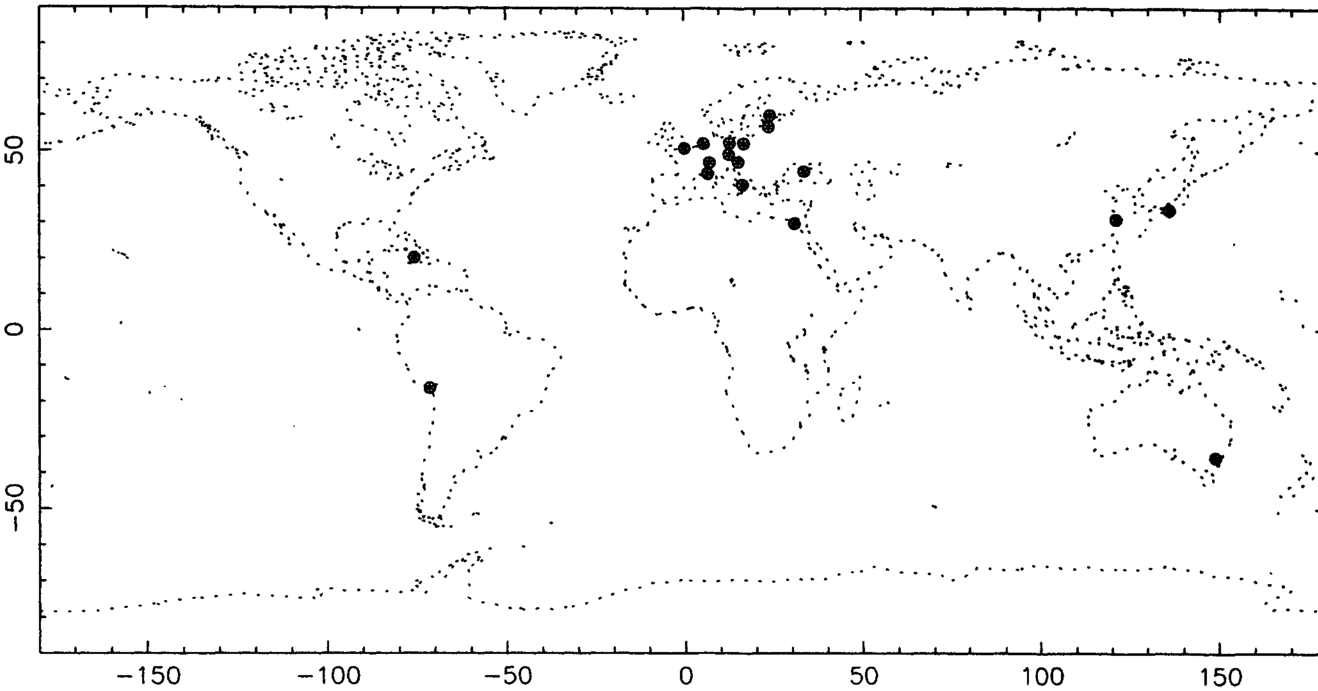
Mean positions of 20 stationary SLR sites have been adjusted to the epoch 1994.0, site velocities were held fixed to those predicted by the NNR-NUVEL1 model.

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).

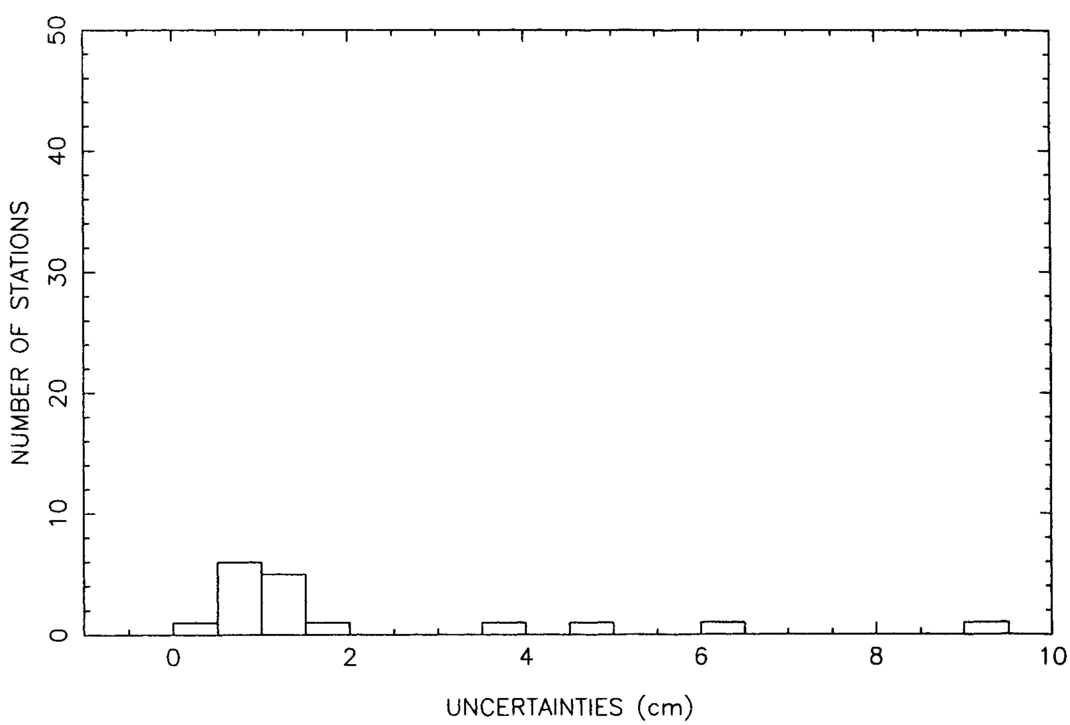
In this solution, corrections to nutation and sites velocities were not adjusted. They will be made when the new program ASTRA is completed.

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 $\sigma_x, \sigma_y, \sigma_z$) 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

DORIS

COORDINATES AND VELOCITIES FROM DORIS TRACKING OF TOPEX/POSEIDON

SSC(CSR) 95 D 01

M. M. Watkins
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G. W. Davis and J. C. Ries
Center for Space Research, The University of Texas at Austin, Austin, USA

Positions and velocities have been computed for 47 separate DORIS beacons. The data set used consisted of 85 cycles (~2.3 years) of tracking data to the Topex/Poseidon satellite. Although a total of over 60 beacons have tracked the Topex/Poseidon and SPOT-n spacecraft, only 47 have sufficient data to estimate a reasonable velocity. The solution was performed without fiducial constraints on any site. Rotational constraints were applied to the network as a whole to remove the rotational singularity, and the network was aligned in rotation and rotation rate to the JCOD7 solution following the method of Heflin *et al.* (1992). Translation (geocenter) and scale are left as estimated from the DORIS data. The force and measurement models generally adhered to the IERS standards and additional references can be found in Watkins *et al.* (1993) and Tapley *et al.* (1994). Specific departures from the IERS standards were:

1) The apriori 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 consituents complete through degree and order 20, assuming admittances which vary linearly with frequency. Some ocean tide coefficients were adjusted using satellite tracking data.

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

Earth rotation parameters were held fixed to the operational series from the University of Texas Center for Space Research CSR94L02 series, a general description of which is found in Eanes and Watkins [1994].

References

Eanes, R. J., Watkins, M. M., 1994: Earth Orientation and Site Coordinates from the Center for Space Research Solution CSR 94 L 01, *IERS Technical Note 17*, P. Charlot (ed.), Observatoire de Paris, Paris, p. L-7.

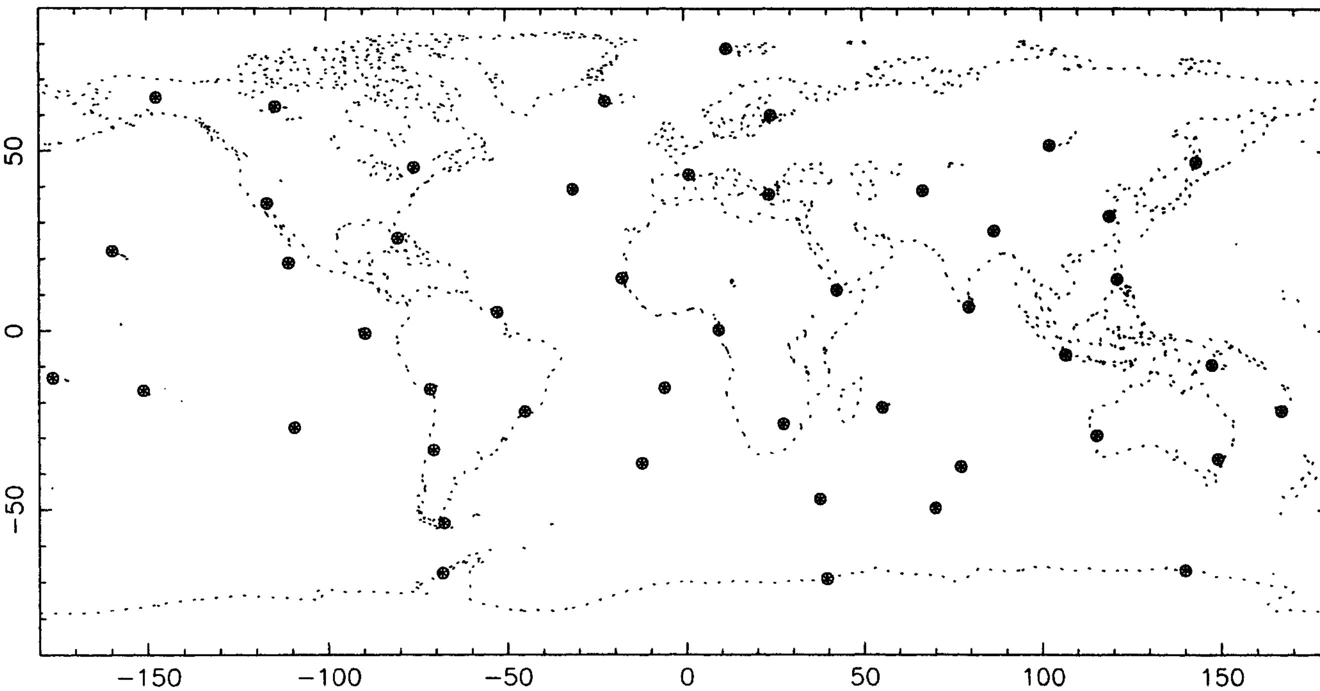
Heflin, M., Bertiger, W., Blewitt, G., Freedman, A., Hurst, K., Lichten, S., Lindqwister, U., Vigue, Y., Webb, F., Yunck, T., Zumberge, J., 1992: Global Geodesy Using GPS Without Fiducial Sites, *Geophys. Res. Lett.*, **19**, No. 2, 131-134.

Tapley, B. D., Ries, J. C., Davis, G. W., Eanes, R. J., Schutz, B. E., Shum, C. K., Watkins, M. M., Marshall, J. A., Nerem, R. S., Putney, B. H., Klosko, S. M., Luthke, S. B., Pavlis, D., Williamson, R. G., Zelensky, N. P., 1994: Precise Orbit Determination for TOPEX/Poseidon, *J. Geophys. Res.*, **99** (C12), 24 383-24 404.

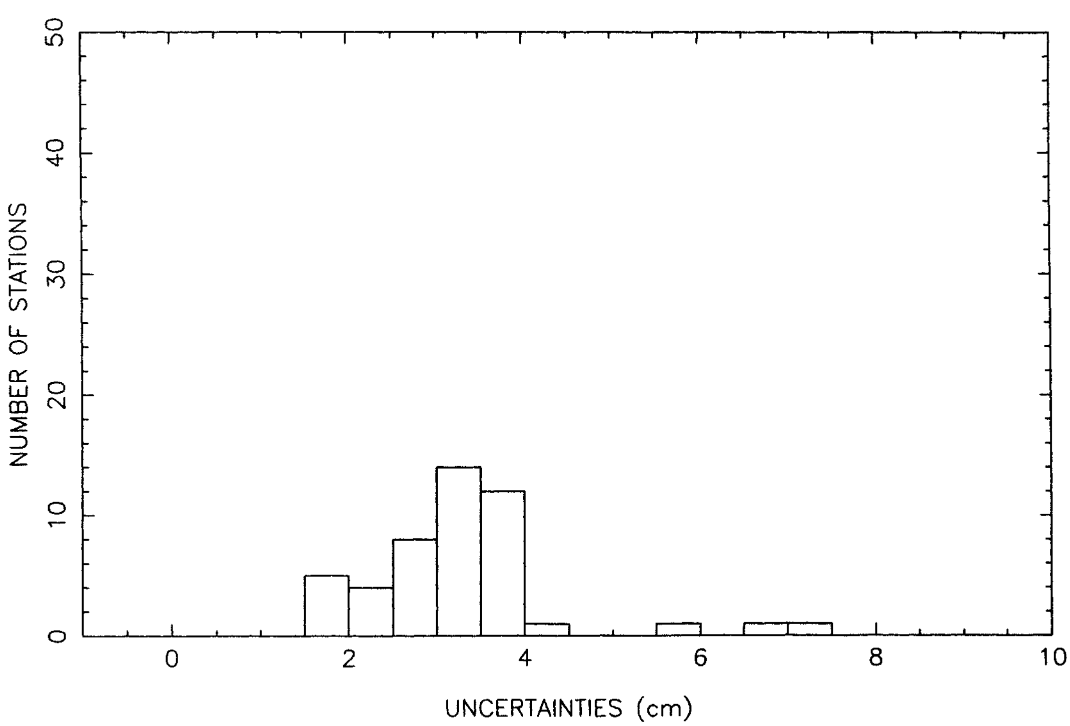
Watkins, M. M., Davis, G. W., Ries, J. C., 1993: Precise Station Coordinate Determination from DORIS tracking of the TOPEX/POSEIDON spacecraft, *Proc. of AAS/AIAA Astrodynamics Specialist Conference,* Paper AAS-93-575, Victoria, Canada.

Technical description of solution CSR 95 D 01

1 - Technique:	DORIS
2 - Analysis Center:	Center for Space Research, The University of Texas/ Jet Propulsion Laboratory, California Institute of Technology
3 - Software used:	UTOPIA GIPSY/OASIS-II routines used for reference frame definition
4 - Data span:	September, 1992 - January, 1995
5 - Celestial Reference Frame:	Not applicable
a - Nature:	Dynamical, Topex/Poseidon
b - Definition of the orientation:	nutation corrections, UT1 tie to VLBI
6 - Terrestrial Reference Frame:	SSC(CSR) 95 D 01
a - Relativity scale:	Local Earth
b - Velocity of light:	299792458 m/sec
c - Geogravitational constant:	GM0 = 3.986004415 10^{14} m^3 s^{-2}
d - Permanent tidal correction:	No
e - Definition of origin:	Defined by satellite dynamics through C10=0, C11= 0,S11=0
f - Definition of orientation:	No net rotation with respect to ITRF93
g - Reference epoch:	1993.0
h - Tectonic plate model:	Estimated/NUVEL1 background
i - Constraint for time evolution:	No net rotation rate with respect to ITRF93
7 - Earth orientation:	Fixed to CSR 94 L 02
a - A priori nutation model:	IAU(1980) + 6 frequency correction formula
b - Short-period tidal variations in x, y, UT1:	Not estimated
8 - Estimated Parameters:	
a - Celestial Frame:	Orbit initial conditions, empirical accelerations per arc.
b - Terrestrial Frame:	X0, Y0, Z0, Xdot, Ydot, Zdot
c - Earth Orientation:	
d - Others:	troposphere correction and frequency offset per pass.



Distribution of the 47 sites of the terrestrial frame SSC(CSR) 95 D 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 47 stations of the terrestrial frame SSC(CSR) 95 D 01.

SITE COORDINATES AND VELOCITIES FROM THE GRGS USING DORIS

SSC(GRGS) 95 D 01

L. Soudarin, J.F. Cretaux and A. Cazenave

Coordinates and velocities for 49 globally distributed sites have been computed using a no-fiducial approach. The DORIS data of 4 years of SPOT2 (September 1990 to December 1994), 2 years of TOPEX/POSEIDON (january 1993 to December 1994) and 14 months of SPOT3 (November 1993 to December 1994) were used for this solution.

Data analysis

The DORIS data are analysed through a dynamical orbit computation in which the satellite orbit, station positions and velocities, and EOP are determined in a single inversion, together with selected parameters required to improve the force model and the measurement corrections. Orbits are computed on a daily basis from which normal equations for station coordinates, velocity vectors and EOP are derived. Individual normal equations of daily orbit computations for each satellite have been accumulated to form a 4-year combined matrix involving data of the three satellites. The inversion of this matrix yields the solution for the geodetic parameters.

The gravity field model used in the orbit computation is GRIM4-C4 with a GM0 different from the IERS Standards.

Estimated parameters

The EOP parameters are being fixed to the EOP (IERS) 90 C 04 before 21/02/1992 and to the IERS bulletin B values after this date.

The stations parameters (positions and velocities) were all estimated, to make the frame entirely free and connected to the IERS only by the EOP.

The sites of Arlit (Niger), Richmond (USA) and Kourou (France) were respectively occupied by two stations which observed over distinct time spans. Because of the short observing periods, velocities were estimated by using the data of the two stations. The stations being close enough, we constrain each couple of stations to have the same velocities. However, for Kourou, the data are unsufficient. The horizontal velocities were so constrained to the NNR-NUVEL1 values and the vertical velocities to 0 mm/yr. Coordinates of the six stations were estimated (with a weak constrain (1 m) on the tie between the pairs of station).

For the sites of Socorro (Mexico), Cibinong (Indonesy), Cachoeira (Brasil), Santiago (Chili) and Dionysos (Greece) with unsufficient data or short observing history, the velocities were constrained to the NNR-NUVEL1 values in horizontal and to 0 mm/yr in vertical.

References

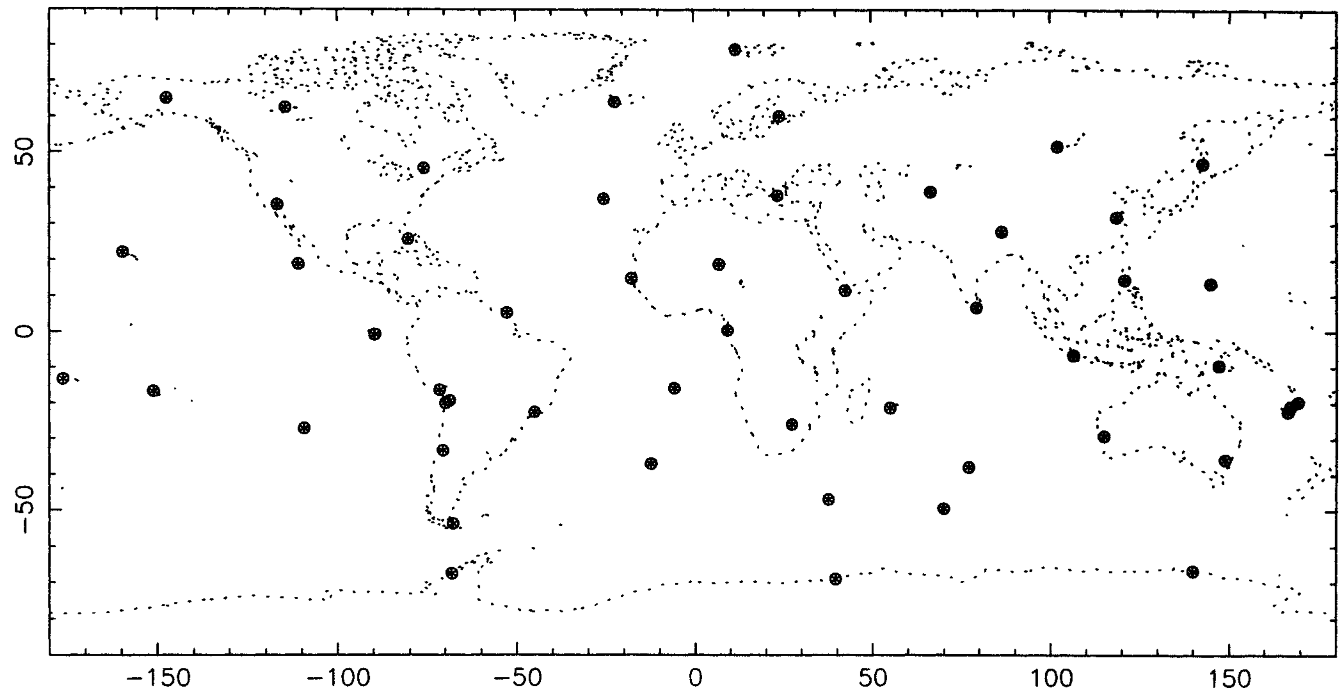
Schwintzer *et al.*, 1995: Long-wavelength global gravity field models: GRIM4-S4, GRIM4-C4, (in preparation).

Soudarin L. and Cazenave C., 1993: Global geodesy using DORIS data on SPOT-2, *Geophys. Res. Lett.*, **20**, No 4, 289-292.

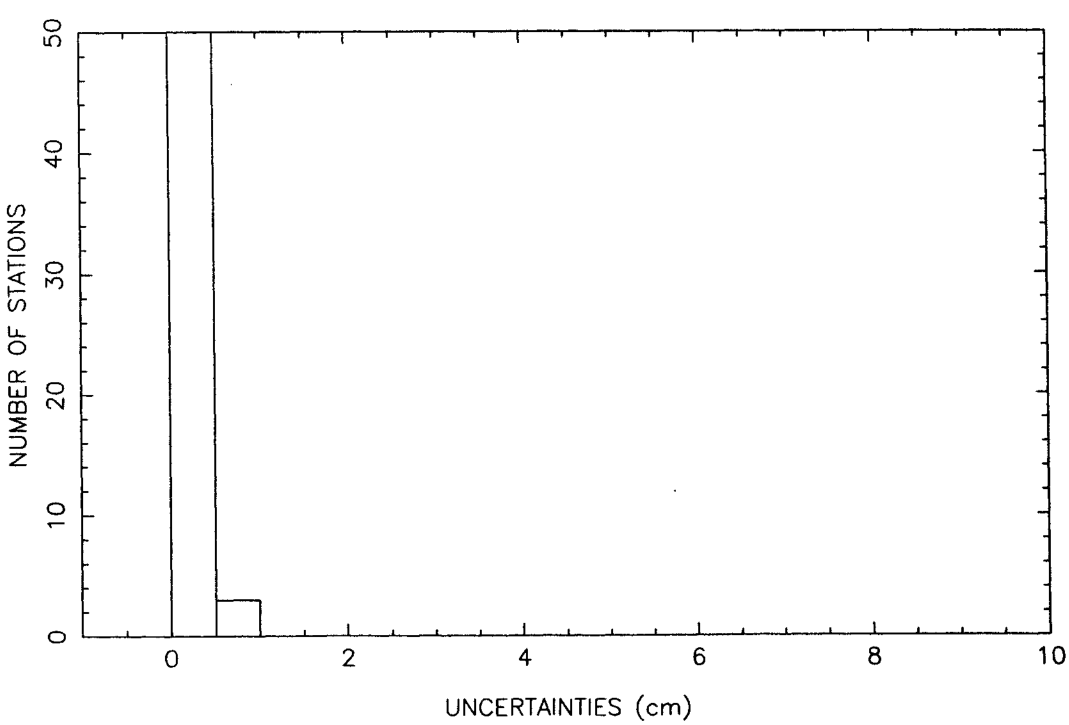
Soudarin L. and Cazenave C., 1995: Large scale tectonic plate motions measured with the DORIS space geodesy system, *Geophys. Res. Lett.,* **22**, No 4, 469-472.

Technical description of solution GRGS 95 D 01

1 - Technique:	DORIS
2 - Analysis Center:	GRGS
3 - Software used:	GINS/DYNAMO
4 - Data span:	Sep 90 - Dec 94
5 - Celestial Reference Frame:	none
a - Nature:	
b - Definition of the orientation:	
6 - Terrestrial Reference Frame:	GRGS 95 D 01
a - Relativity scale:	Local Earth
b - Velocity of light:	299 792 458 m/s
c - Geogravitational constant:	GM0 = 3.98600437 10^{14} m^3/s^2
d - Permanent tidal correction:	Yes
e - Definition of the origin:	Geocentric, C10=C11=S11=0.0
f - Definition of the orientation:	daily EOP fixed to EOP(IERS) 90 C 04 series and IERS bulletin B
g - Reference epoch:	1993.0
h - Tectonic plate model:	NNR-NUVEL1
i - Constraint for time evolution:	For 7 sites with unsufficient data or short observing history, velocities were estimated but strongly constrained to the NNR-NUVEL1 values for the horizontal velocities and to 0 mm/yr for the vertical velocities.
7 - Earth Orientation:	none
a - A priori nutation model:	
b - Short-period tidal variations in x, y, UT1:	
8 - Estimated parameters:	
a - Celestial Frame:	
b - Terrestrial Frame:	X0, Y0, Z0, Xdot, Ydot, Zdot, of 49 DORIS sites
c - Earth Orientation:	
d - Others:	All satellite epoch states, wet zenith tropospheric delays per station and per pass, frequency bias per station and per pass, radiation pressure and drag coefficients once per revolution coefficients.



Distribution of the 52 sites of the terrestrial frame SSC(GRGS) 95 D 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 54 stations of the terrestrial frame SSC(GRGS) 95 D 01.

COORDINATES AND VELOCITIES FROM DORIS TRACKING OF TOPEX/POSEIDON

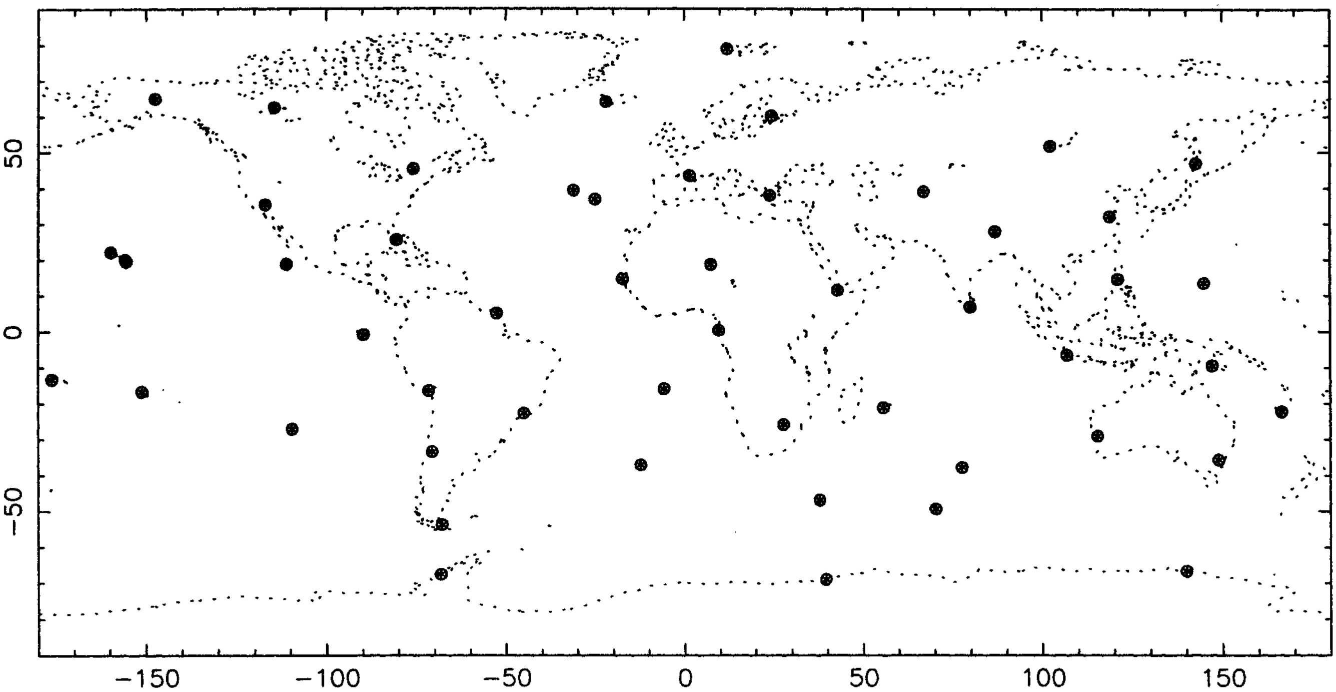
SSC(IGN) 95 D 02

Pascal Willis - Institut Géographique National, Saint-Mandé, France

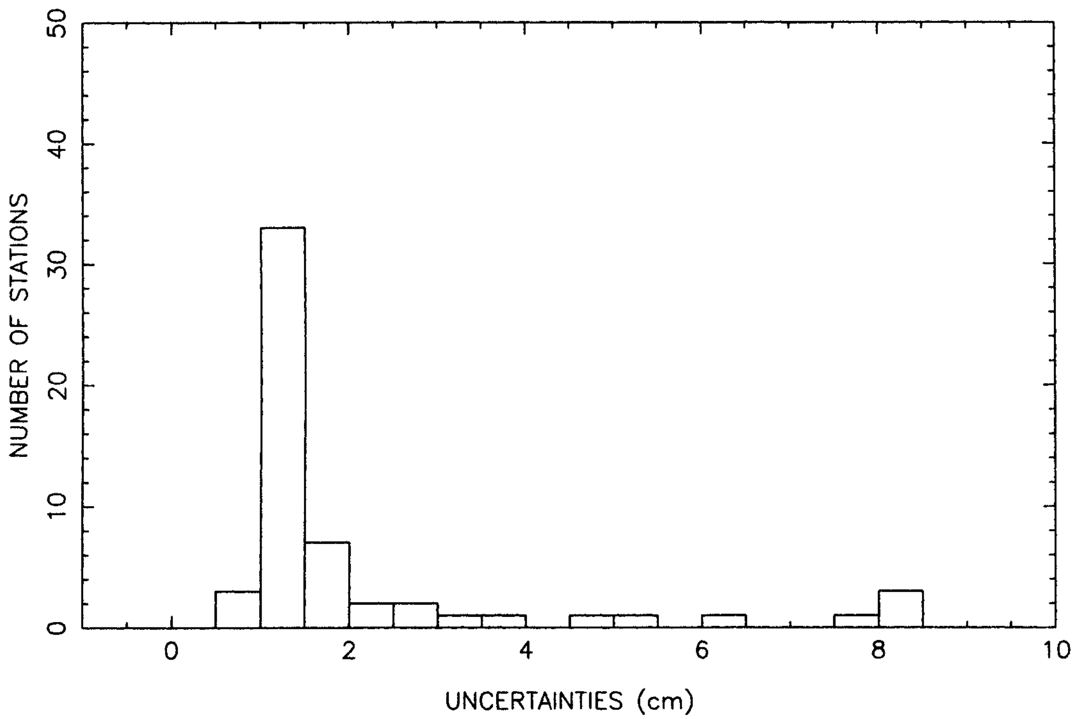
The DORIS data from the Topex/Poseidon were used (october 1992-february 1995). The data were computed on a daily basis using the free network approach (estimating simultaneously the stations positions and velocities and earth rotation parameters (pole+UT1-UTC rate)). These daily files were combined in a global adjustment. The initial constrains are very loose (1 km for the stations positions and the pole). After this adjustment, rotational constraints were applied to the JCOD7 solution using the Heflin method. For the pole solution, the constraints were applied for translation, rotation and scale. For the terrestrial solution, only constraints in rotation were applied (the geocenter and the scale then come from the DORIS data adjustment only). The main difference with the IERS standard is the use of the JGM3 70*70 gravity field.

Technical description of solution IGN 95 D 02

1 - Technique:	DORIS
2 - Analysis Center:	IGN, Saint-Mandé, France
3 - Software used:	GIPSY/OASIS-II
4 - Data span:	October, 1992 - February, 1995
5 - Celestial Reference Frame:	Not applicable
a - Nature:	Dynamical, Topex/Poseidon
b - Definition of the orientation:	
6 - Terrestrial Reference Frame:	SSC(IGN) 95 D 02
a - Relativity scale:	Local Earth
b - Velocity of light:	299792458 m/sec
c - Geogravitational constant:	GM0 = 3.986004415 10^{14} m^3 s^{-2}
d - Permanent tidal correction:	No
e - Definition of origin:	Defined by satellite dynamics through C10=0, C11=0, S11=0
f - Definition of orientation:	No net rotation with respect to JCOD7
g - Reference epoch:	1993.0
h - Tectonic plate model:	Estimated
i - Constraint for time evolution:	No net rotation rate with respect to JCOD7
7 - Earth orientation:	
a - A priori nutation model:	
b - Short-period tidal variations in x, y, UT1:	Not estimated
8 - Estimated Parameters:	
a - Celestial Frame:	Orbit initial conditions, empirical accelerations per arc.
b - Terrestrial Frame:	X0, Y0, Z0, Xdot, Ydot, Zdot
c - Earth Orientation:	XPOLE, YPOLE, UT1-UTCRATE
d - Others:	troposphere correction and frequency offset per pass.



Distribution of the 52 sites of the terrestrial frame SSC(IGN) 95 D 02.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 56 stations of the terrestrial frame SSC(IGN) 95 D 02.

COMBINATION

A COMBINATION OF EOP MEASUREMENTS: SPACE94 EOP(JPL) 95 C 01

R. S. Gross (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109-8099, USA; rsg@logos.jpl.nasa.gov)

A combination of independently-determined Earth orientation data has been generated from space-geodetic observations spanning 1976-1994. The approach taken is the same as that used in generating previous such combinations (Gross, IERS Technical Note 17, pp. C5-C13, 1994) and will be only briefly described here. Since it was desirable to combine only independent determinations of the Earth's orientation, only those series listed in Table 1 were used. Note that only the Scripps GPS measurements through May 31, 1992 were used, with the JPL GPS measurements being used thereafter. Similarly, only the USNO IRIS Intensive UT1 determinations made after January 1, 1995 were used, with the NOAA IRIS Intensive series being used before then.

Prior to their combination, the bias and rate of each series was iteratively adjusted so as to be in agreement with the bias and rate exhibited by a combination of all other series; the stated uncertainty of each series was adjusted by applying a multiplicative scale factor that made the residual of that data, when differenced with a combination of all other data, have a reduced chi-square of one; and those data points whose residual values were greater than three times their adjusted uncertainties were deleted. In order for the final combination, SPACE94, to be given within a well-defined terrestrial reference frame, an additional bias-rate correction was determined for each series by aligning it with the IERS Earth orientation series EOP(IERS) 90 C 04. The total bias-rate corrections and uncertainty scale factors that have been applied to the individual series prior to their combination into SPACE94 are given in Table 1 in the natural reference frame for each data type: the transverse (T), vertical (V) frame for single baseline VLBI measurements; the variation-of-latitude (LAT), UT0 frame for single station LLR measurements; and the usual UTPM (PMX, PMY, UT1) frame for all other measurements. The errors in the bias-rate corrections (given in parentheses in Table 1) are the formal errors in determining the incremental bias-rate corrections during the last iteration of the iterative, round-robin procedure. There are no bias-rate entries in Table 1 for components that were either not used or not available.

The resulting EOP combination, SPACE94, spans October 6, 1976 to January 27, 1995 at 1-day intervals. The EOP values reported here do not include diurnal and semi-diurnal tidal variations since they have not been added back after being removed, when necessary, from the measurements prior to their combination.

Acknowledgments. I would like to thank all those involved in taking and reducing the raw Earth orientation measurements that have been combined into SPACE94. This study would not have been possible without their considerable efforts. The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Table 1. Adjustments to data sets prior to combination

DATA SET NAME	BIAS (mas)			RATE (mas/yr)			UNCERTAINTY SCALE FACTOR		
LLR (JPL94M01)	LAT	UT0		LAT	UT0		LAT	UT0	
McDonald Cluster	2.296	0.903		-0.724	-0.111		1.379	1.189	
	(0.237)	(0.231)		(0.046)	(0.051)				
CERGA	-0.284	0.348		0.122	-0.060		1.799	1.301	
	(0.179)	(0.096)		(0.037)	(0.022)				
Haleakala	1.421	-0.627		-0.208	-0.065		1.530	1.788	
	(0.275)	(0.235)		(0.180)	(0.160)				
DSN (JPL94R01)	T	V		T	V		T	V	
CA-Spain Cluster	0.942	-0.328		-0.009	0.020		1.417	1.186	
	(0.072)	(0.171)		(0.016)	(0.039)				
CA-Australia Cluster	0.356	0.701		-0.250	0.078		1.465	1.219	
	(0.050)	(0.147)		(0.012)	(0.035)				
CDP (GLB973f)	T	V		T	V		T	V	
Westford-Ft. Davis	4.664	0.330		0.723	-0.191		0.363	0.769	
	(1.839)	(3.183)		(0.371)	(0.634)				
Westford-Mojave	0.443	0.723		-0.037	0.019		2.586	0.998	
	(0.217)	(0.455)							
CDP (GLB973f)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
Multi	-0.435	-1.690	1.074	-0.140	-0.060	-0.121	2.114	1.974	2.143
	(0.027)	(0.023)	(0.031)	(0.007)	(0.005)	(0.007)			
UTCSR (94L01)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
LAGEOS	0.116	0.582	---	-0.058	-0.162	---	0.704	0.602	---
	(0.023)	(0.019)		(0.007)	(0.006)				
NOAA (19JAN95)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
IRIS Inten.	---	---	1.110	---	---	-0.075	---	---	0.947
			(0.027)			(0.007)			
GPS (SIO93P01)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
Scripps	-0.818	-1.508	---	-0.040	-0.002	---	1.899	1.915	---
	(0.035)	(0.040)							
GPS (JPL95P01)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
JPL FLINN	-0.246	0.455	---	0.028	-0.135	---	3.457	2.952	---
	(0.144)	(0.130)		(0.024)	(0.022)				
USNO (23FEB95)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
IRIS Inten.	---	---	-0.239	---	---	-0.010	---	---	1.578
			(0.042)						

Reference date for rate adjustment is 1988.0

Technical description of solution JPL 95 C 01

1 - Techniques:	Combined
2 - Analysis Center:	JPL
3 - Software used:	Kalman Earth Orientation Filter (KEOF)
4 - Data span:	Oct 76 - Jan 95 at 1-day intervals
5 - Celestial Reference Frame:	Not Applicable
a - Nature:	
b - Definition of the orientation:	
6 - Terrestrial Reference Frame:	Not Applicable
a - Relativity scale:	
b - Velocity of light:	
c - Geogravitational constant:	
d - Permanent tidal correction:	
e - Definition of origin:	
f - Definition of orientation:	
g - Reference epoch:	
h - Tectonic plate model:	
i - Constraint for time evolution:	
7 - Earth orientation:	EOP(JPL) 95 C 01
a - A priori nutation model:	Not Applicable
b - Short-period tidal variations in x, y, UT1:	When necessary, the diurnal and semi-diurnal tidal variations have been removed from the individual EOP series prior to their combination into EOP(JPL) 95 C 01. The diurnal and semi-diurnal tidal terms have not been added back to the values reported in EOP(JPL) 95 C 01.
c - Definition of the reference frame:	EOP(JPL) 95 C 01 has been aligned with the IERS combined Earth orientation series EOP(IERS) 90 C 04 during 1984-1994 and is therefore given within that reference frame defined by EOP(IERS) 90 C 04.
8 - Estimated Parameters:	
a - Celestial Frame:	
b - Terrestrial Frame:	
c - Earth Orientation:	PMX, PMY, UT1-UTC
d - Others:	

EOP(JPL) 95 C 01 From Oct 1976 to Jan 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	87	3.68	87	2.90	87	8.90
1977	365	3.38	365	2.60	365	4.45
1978	365	3.57	365	2.41	365	5.65
1979	365	2.95	365	2.29	365	4.28
1980	366	1.53	366	0.96	366	2.82
1981	365	1.27	365	0.94	365	1.73
1982	365	0.96	365	0.78	365	1.17
1983	365	0.83	365	0.76	365	0.93
1984	366	0.49	366	0.41	366	0.51
1985	365	0.41	365	0.34	365	0.33
1986	365	0.36	365	0.30	365	0.29
1987	365	0.29	365	0.24	365	0.28
1988	366	0.25	366	0.22	366	0.25
1989	365	0.25	365	0.22	365	0.22
1990	365	0.21	365	0.19	365	0.19
1991	365	0.21	365	0.19	365	0.19
1992	366	0.17	366	0.15	366	0.16
1993	365	0.16	365	0.14	365	0.18
1994	365	0.14	365	0.13	365	0.21
1995	27	0.17	27	0.15	27	0.23

COMBINATIONS OF EOP MEASUREMENTS: COMB94 & POLE94

EOP(JPL) 95 C 02
EOP(JPL) 95 C 03

R. S. Gross (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109-8099, USA, rsg@logos.jpl.nasa.gov)

A Kalman filter has been used to combine independent measurements of the Earth's orientation taken by optical astrometry and the space-geodetic techniques of LLR, SLR, VLBI, and GPS. Prior to incorporation of the optical astrometric measurements, the space-geodetic measurements were first combined together, resulting in the combined EOP series EOP (JPL) 95 C 01 (a.k.a. SPACE94), the description of which can be found elsewhere in this volume. The incorporation of the optical astrometric measurements was then done in two stages: (1) the BIH optical astrometric series (Li, BIH Annual Report for 1984, pp. D31-D63) was first combined with SPACE94 to form COMB94, and (2) the International Latitude Service (ILS) optical astrometric series (Yumi and Yokoyama, Results of the ILS in a Homogeneous System, 1980) was combined with COMB94 to form POLE94.

Prior to forming COMB94, the BIH astrometric series was first corrected to have the same bias and rate as SPACE94, the stated measurement uncertainties of the BIH series were adjusted by applying a constant multiplicative scale factor that made the BIH residual, when differenced with SPACE94, have a reduced chi-square of one; and those BIH data points whose residual values were greater than three times their adjusted uncertainties were deleted. In addition, in order to correct for systematic, seasonally varying effects in optical astrometric measurements, the annual term of the BIH series was adjusted to be in agreement with the annual term exhibited by SPACE94. The corrections thus determined and applied to the BIH series prior to its combination with SPACE94 are shown in Tables 1 and 2, with the 1-sigma formal uncertainties in determining these bias, rate, and annual term corrections being shown in parentheses.

The result of combining the corrected BIH optical astrometric EOP measurements with SPACE94 is designated EOP(JPL) 95 C 02 (a.k.a. COMB94), spans January 20, 1962 to January 27, 1995 at 5- day intervals, and consists of values of PMX, PMY, UT1-UTC, their 1-sigma formal uncertainties, and correlations.

The ILS optical astrometric series was then combined with COMB94 to form POLE94 after first: (1) correcting the ILS series to have the same bias, rate, and annual term as COMB94, (2) applying a constant multiplicative scale factor to the stated measurement uncertainties of the ILS series so that its residual, when differenced with COMB94, had a reduced chi-square of one, and (3) deleting those data points whose residual values were greater than three times their adjusted uncertainties (see Tables 1 and 2 for the values of the corrections applied to the ILS series). The result of combining the corrected ILS optical astrometric EOP measurements with COMB94 is designated EOP(JPL) 95 C 03 (a.k.a. POLE94), spans January 20, 1900 to January 21, 1995 at 30.4375-day intervals, and consists of values of PMX and PMY, their 1-sigma formal uncertainties, and correlations.

Acknowledgments. The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Table 1. Adjustments to bias, rate, and uncertainty

DATA SET NAME	BIAS (mas)			RATE (mas/yr)			UNCERTAINTY SCALE FACTOR		
	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
BIH	7.993	6.035	35.094	1.030	0.414	5.251	1.830	1.601	1.865
	(4.280)	(1.893)	(2.937)	(0.483)	(0.180)	(0.316)			
ILS	-49.540	7.389	---	0.053	-0.876	---	1.999	1.599	---
	(2.177)	(1.747)		(0.444)	(0.356)				

Reference date for rate adjustment of BIH series is 1988.0
Reference date for rate adjustment of ILS series is 1970.0

Table 2. Adjustment to annual component

DATA SET NAME	COEFFICIENT OF SINE TERM (mas)			COEFFICIENT OF COSINE TERM (mas)		
	PMX	PMY	UT1	PMX	PMY	UT1
BIH	-5.627	-6.749	5.322	-2.799	9.824	-0.922
	(1.017)	(0.621)	(0.781)	(1.069)	(0.683)	(0.832)
ILS	-0.406	8.055	---	10.036	-10.922	---
	(3.059)	(2.453)		(3.063)	(2.457)	

Reference date for adjustment of BIH series is 1988.0
Reference date for adjustment of ILS series is 1970.0

Technical description of solution JPL 95 C 02

1 - Techniques:	Combined
2 - Analysis Center:	JPL
3 - Software used:	Kalman Earth Orientation Filter (KEOF)
4 - Data span:	Jan 1962 - Jan 1995 at 5-day intervals
5 - Celestial Reference Frame:	Not Applicable
a - Nature:	
b - Definition of the orientation:	
6 - Terrestrial Reference Frame:	Not Applicable
a - Relativity scale:	
b - Velocity of light:	
c - Geogravitational constant:	
d - Permanent tidal correction:	
e - Definition of origin:	
f - Definition of orientation:	
g - Reference epoch:	
h - Tectonic plate model:	
i - Constraint for time evolution:	
7 - Earth orientation:	EOP(JPL) 95 C 02 (a.k.a. COMB94)
a - A priori nutation model:	Not Applicable
b - Short-period tidal variations in x, y, UT1:	When necessary, the diurnal and semi-diurnal tidal variations have been removed from the individual EOP series prior to their combination into EOP(JPL) 95 C 02. The diurnal and semi-diurnal tidal terms have not been added back to the values reported in EOP(JPL) 95 C 02.
c - Definition of the reference frame:	EOP(JPL) 95 C 02 has been aligned with EOP(JPL) 95 C 01 which was in turn aligned with the IERS combined Earth orientation series EOP(IERS) 90 C 04 during 1984-1994. EOP(JPL) 95 C 02 is therefore given within that reference frame defined by EOP (IERS) 90 C 04.
8 - Estimated Parameters:	
a - Celestial Frame:	
b - Terrestrial Frame:	
c - Earth Orientation:	PMX, PMY, UT1-UTC
d - Others:	

Technical description of solution JPL 95 C 03

1 - Techniques:	Combined
2 - Analysis Center:	JPL
3 - Software used:	Kalman Earth Orientation Filter (KEOF)
4 - Data span:	Jan 1900 - Jan 1995 at 30.4375-day intervals
5 - Celestial Reference Frame:	Not Applicable
a - Nature:	
b - Definition of the orientation:	
6 - Terrestrial Reference Frame:	Not Applicable
a - Relativity scale:	
b - Velocity of light:	
c - Geogravitational constant:	
d - Permanent tidal correction:	
e - Definition of origin:	
f - Definition of orientation:	
g - Reference epoch:	
h - Tectonic plate model:	
i - Constraint for time evolution:	
7 - Earth orientation:	EOP(JPL) 95 C 03 (a.k.a. POLE94)
a - A priori nutation model:	Not Applicable
b - Short-period tidal variations in x, y, UT1:	When necessary, the diurnal and semi-diurnal tidal variations have been removed from the individual EOP series prior to their combination into EOP(JPL) 95 C 03. The diurnal and semi-diurnal tidal terms have not been added back to the values reported in EOP(JPL) 95 C 03.
c - Definition of the reference frame:	EOP(JPL) 95 C 03 has been indirectly aligned with the IERS combined Earth orientation series EOP(IERS) 90 C 04 during 1984-1994. EOP(JPL) 95 C 03 is therefore given within that reference frame defined by EOP (IERS) 90 C 04.
8 - Estimated Parameters:	
a - Celestial Frame:	
b - Terrestrial Frame:	
c - Earth Orientation:	PMX, PMY
d - Others:	

EOP(JPL) 95 C 02 From Jan 1962 to Jan 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
1962	69	8.40	69	7.28	69	9.67
1963	73	8.78	73	7.57	73	10.00
1964	73	8.08	73	7.21	73	9.17
1965	73	8.36	73	7.14	73	9.16
1966	73	8.21	73	7.16	73	9.12
1967	73	6.55	73	5.95	73	7.57
1968	73	6.76	73	5.88	73	7.82
1969	73	6.04	73	5.68	73	7.24
1970	73	6.02	73	5.53	73	7.06
1971	73	5.57	73	4.65	73	5.83
1972	73	5.11	73	3.36	73	4.18
1973	73	5.15	73	3.75	73	4.16
1974	73	5.15	73	3.91	73	4.50
1975	73	5.14	73	3.55	73	4.09
1976	73	5.19	73	3.45	73	4.37
1977	73	3.04	73	2.38	73	3.73
1978	73	3.16	73	2.26	73	4.26
1979	73	2.77	73	2.14	73	3.65
1980	74	1.50	74	0.96	74	2.68
1981	73	1.24	73	0.94	73	1.67
1982	73	0.95	73	0.77	73	1.22
1983	73	0.84	73	0.76	73	0.87
1984	73	0.48	73	0.40	73	0.37
1985	73	0.40	73	0.33	73	0.25
1986	73	0.36	73	0.29	73	0.22
1987	73	0.28	73	0.24	73	0.21
1988	73	0.24	73	0.22	73	0.18
1989	73	0.24	73	0.21	73	0.17
1990	73	0.21	73	0.18	73	0.14
1991	73	0.20	73	0.18	73	0.16
1992	73	0.17	73	0.16	73	0.16
1993	73	0.16	73	0.14	73	0.19
1994	73	0.14	73	0.13	73	0.21
1995	6	0.17	6	0.15	6	0.19

EOP(JPL) 95 C 03 From Jan 1900 to Jan 1995

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

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1900	12	19.00	12	16.17
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
1961	12	19.00	12	16.17
1962	12	8.01	12	6.98
1963	12	8.32	12	7.21
1964	12	7.83	12	6.90
1965	12	7.94	12	6.82
1966	12	7.93	12	6.89
1967	12	6.37	12	5.74
1968	12	6.59	12	5.68
1969	12	5.94	12	5.57
1970	12	5.87	12	5.41
1971	12	5.48	12	4.52
1972	12	5.02	12	3.23
1973	12	5.09	12	3.64
1974	12	5.07	12	3.94
1975	12	4.97	12	3.50
1976	12	5.14	12	3.37
1977	12	3.07	12	2.51
1978	12	3.15	12	2.21
1979	12	2.58	12	2.20
1980	12	1.48	12	0.94
1981	12	1.13	12	0.87
1982	12	0.97	12	0.78
1983	12	0.83	12	0.74
1984	12	0.48	12	0.41
1985	12	0.38	12	0.32
1986	12	0.38	12	0.32
1987	12	0.27	12	0.23
1988	12	0.25	12	0.21
1989	12	0.25	12	0.21
1990	12	0.23	12	0.20
1991	12	0.22	12	0.21
1992	12	0.14	12	0.13
1993	12	0.15	12	0.13
1994	12	0.15	12	0.13
1995	1	0.17	1	0.15

COMBINATION OF PRECISE OBSERVATIONS OF THE ORIENTATION OF THE EARTH

NEOS 95 C 01

[The procedure for obtaining this series is described in the IERS Annual Report for 1994, part. III].

EOP(NEOS) 95 C 01 From May 1976 to Dec 1994

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

YEAR	X		Y		UT1		$\delta\psi$		$\delta\epsilon$	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
1976	226	3.31	226	2.76	226	4.02				
1977	365	3.72	365	4.51	365	3.25				
1978	365	4.95	365	3.87	365	3.28				
1979	365	3.10	365	2.69	365	2.71	144	1.98	144	0.87
1980	366	2.35	366	1.40	366	2.60	366	1.98	366	0.87
1981	365	3.21	365	2.40	365	2.71	365	1.98	365	0.87
1982	365	1.70	365	1.72	365	2.73	365	1.98	365	0.87
1983	365	1.08	365	1.02	365	2.02	365	1.98	365	0.87
1984	366	0.72	366	0.75	366	0.57	366	0.79	366	0.26
1985	365	0.68	365	0.61	365	0.45	365	0.75	365	0.28
1986	365	0.67	365	0.65	365	0.39	365	0.79	365	0.26
1987	365	0.67	365	0.67	365	0.45	365	0.82	365	0.30
1988	366	0.60	366	0.51	366	0.40	366	0.67	366	0.25
1989	365	0.54	365	0.54	365	0.41	365	0.60	365	0.21
1990	365	0.56	365	0.53	365	0.39	365	0.65	365	0.22
1991	365	0.50	365	0.49	365	0.40	365	0.65	365	0.24
1992	366	0.17	366	0.17	366	0.38	366	0.68	366	0.21
1993	365	0.10	365	0.09	365	0.42	365	0.47	365	0.23
1994	365	0.10	365	0.10	365	0.33	365	0.47	365	0.30

ATMOSPHERIC ANGULAR MOMENTUM

EFFECTIVE ATMOSPHERIC ANGULAR MOMENTUM FUNCTIONS COMPUTED FROM THE JAPAN METEOROLOGICAL AGENCY DATA

AAM(JMA) 87 * 01

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The effective atmospheric angular momentum (EAAM) functions proposed by Barnes *et al.* (1983) have been computed from the global analysis data provided by the Japan Meteorological Agency (JMA) since September 28, 1983. In general, the operational numerical weather prediction produces the three data sets called the analysis-phase analysis data, the initialized phase analysis data and the predicted values. The JMA global analysis data are the analysis-phase analysis data. For the use of this file, it should be noticed that the results during 1983/12/1 - 1986/6/30 are once-a-day values computed from daily mean global data of the JMA global analysis data averaged at each grid and each level, otherwise twice-a-day (00 UT and 12 UT) values computed without averaging.

The JMA global analysis data have been made on 1.875-degree (2.5-degree before 1988/3/1) latitude-longitude grid system at sixteen levels (fifteen levels before 1988/3/1) up to ten millibars by the following analysis and forecast models. The analysis model is based on a multi-variate optimum interpolation method in troposphere and on a sinusoidal fitting method in stratosphere, with the initial guess of six-hour forecast and the cut-off time of six hours after map time. The forecast model is based on a 1.875-degree (2.5-degree before 1988/3/1) and sixteen-level (twelve-level before 1988/3/1) global spectral model after a non-linear normal mode initialization with physics. The model has a horizontal resolution of triangular truncation at wavenumber 63 (42 before 1988/3/1) and incorpolates full physical processes. The details for the analysis and forecast models after 1988/3/1 can be found in Kitade (1988), Kashiwagi (1987) and Kanamitsu *et al.* (1983) for those before 1988/3/1.

For computing the EAAM functions, the sea level pressure, the geopotential height and the wind velocities at each level are used. In addition, mountain heights of the same grid system are used for estimating surface pressures on land and for computing sea level pressures on ocean with the Inverted Barometer (IB) hypothesis. The surface pressures on mountains are computed from the geopotential heights by using a cubic spline interpolation technique with estimating the thickness temperatures by the same techniques. Vertical integrations of the wind terms of the EAAM functions are done from surface pressure on land (or the sea level pressure on ocean) to ten millibars. The integral formula to evaluate the EAAM functions are basically due to the equations (5.1), (5.2) and (5.3) of Barnes *et al* (1983), but the axial component of the EAAM functions is due to the equation (5.3) multiplied by -1 for convenience. No smoothing have been done after evaluation. Details of the evaluation can be found in Naito *et al.* (1987).

Acknowledgements. The authors thank the staff of the Numerical Prediction Division, the Japan Meteorological Agency, for supporting this work.

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AAM(JMA) 87 * 01 From 1983 to 1994

Year	Number of Measurements
1983	150
1984	357
1985	365
1986	549
1987	730
1988	732
1989	730
1990	730
1991	730
1992	1120
1993	1440
1994	1228

EFFECTIVE ATMOSPHERIC ANGULAR MOMENTUM FUNCTIONS AND RELATED PARAMETERS COMPUTED AT THE U.S. NATIONAL METEOROLOGICAL CENTER

AAM(NMC) 87 * 01

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1. Introduction

As described in the *IERS Technical Note 2*, twice daily analysis values of effective atmospheric angular momentum (EAAM) functions (Barnes *et al.*, 1983) have been calculated from NMC global analyses throughout 1994. These include variables which relate to Earth rotation and polar motion. Starting 1 October 1989, the operational start date of the SBAAM, a more complete set of analysis and forecast values of EAAM functions and related analysis parameters have been produced.

2. SBAAM Data

Following Sub-Bureau specifications, two files have been produced by NMC beginning 1 October 1989. The first, an analysis file, contains hemispheric values of the EAAM functions χ_1, χ_2, and χ_3, each of which is further partitioned into wind, pressure, and pressure + inverted barometer components. The Sub-Bureau also requested that wind terms be calculated to 100 mb, as well as to the top of the model; however, this is done only for the χ_3 term. As a result of an earlier formulation, all NMC χ_3 values calculated before October 1989 were multiplied by a minus sign. This was stopped on 1 October 1989. This file also contains analyses of zonal mean zonal wind, zonal mean temperatures, mean surface pressure and low order spectral coefficients of surface pressure. With the exception of the surface pressure fields, all analysis parameters and EAAM functions are derived from an initialized global analysis. The complete analysis file is produced twice daily, at 00 and 12 UTC. The second file contains 21 sets of forecast values (00-h to 240-h) of the EAAM functions at 12-hour intervals starting at 00 UTC. These values are globally integrated. A more complete description of both files is found in Table 1.

These data are archived monthly, and are also available from a dial-up service at NMC. The analysis file and forecast file are transferred once daily are maintained on a 10-day rotating file. An additional file is produced for the dial-up service only and contains hemispheric values of the EAAM functions and forecast values of zonal mean zonal winds. Complete information on the NMC files and dial-up system is found in a NMC User's Guide, available from the Sub-Bureau.

3. NMC Global Analysis and Forecast System

The NMC global data assimilation and forecast system is described in detail by Kanamitsu (1989). The global analyses are produced every 6 hours with an intermittent assimilation of data that uses a 6-h forecast as an initial guess. A diabatic nonlinear normal mode initialization procedure is performed on the analyses and is necessary for dynamic balance. The initialization procedure was changed on 14 December 1989 to a procedure which initializes only the analysis increments. This new procedure reduces the effect of the initialization on the analyses.

Table 1. Content of SBAAM Files

Variable	Analysis File Specification	Array size
$\chi_2, \chi_2, \chi_2,$	hemispheric values of wind to 100mb, wind to top of model (50mb), pressure, pressure + inverted barometer	(8,3)
zonal mean zonal wind (m/s)	5 degree latitude bands, 12 mandatory pressure levels (1000 - 50mb)	(37,12)
zonal mean temperature (K)	5 degree latitude bands, 12 mandatory pressure levels (1000 - 50 mb)	(37,12)
mean global surface pressure (mb)		(1)
low-order spherical harmonics of surface pressure	4 wave, triangular truncation 20 wave, zonals only with and without inverted barometer	(30) (21) (30) (21)
	Forecast File	
$\chi_2, \chi_2, \chi_2,$	global values of wind to 100 mb, wind to top of model, pressure, pressure + inverted barometer; forecast lead times every 12 hours (00-h to 240-h)	21 arrays of (4,3)

The NMC global forecast model has 18 vertical sigma layers and a horizontal resolution of 80 waves with triangular truncation. The EAAM functions are calculated after a vertical interpolation from the sigma coordinates to constant pressure levels (1000 mb to 50 mb) and a grid with horizontal resolution of 2.5 lat/lon. Therefore, wind integrals are calculated to 50 mb. Pressure terms are calculated on the model surface, where the orography is an enhancement of silhouette orography (Mesinger *et al.*, 1988). On 14 December 1989 changes were implemented in the surface physics package which were designed to result in a more realistic cycle and pattern of evaportation. It is felt that this change will result in minor changes in the forecasted surface pressure.

Results of some of the NMC calculations are shown in the 1994 IERS Annual Report.

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AAM(NMC) 87 * 01 From 1976 to 1994

Year	Number of meas.	Year	Number of meas.
1976	182	1986	696
1977	358	1987	722
1978	352	1988	679
1979	333	1989	711
1980	326	1990	720
1981	630	1991	718
1982	630	1992	1100
1983	656	1993	1429
1984	679	1994	1436
1985	686		

EFFECTIVE ATMOSPHERIC ANGULAR MOMENTUM FUNCTIONS CALCULATED AT THE U.K. METEOROLOGICAL OFFICE

AAM(UKMO) 83 *01

Throughout 1994, 00-hour and forecast values of effective atmospheric angular momentum (EAAM) functions as described by Barnes *et al.* (1983) have been calculated twice daily, from 00 and 12 UTC. The functions are archived at 24 hour intervals to 6 days, the limit of the UKMO global model. The matter terms are calculated without applying the inverted barometer correction. The UKMO global model and data assimilation have been described in the *IERS Technical Note 2.* Changes are routinely documented in each "Quarterly report on numerical products from Bracknell."

The UKMO forecast file is sent to the Sub-Bureau every three months. Starting in mid-1990, twice daily transmissions of these data will be completed using the GTS data link.

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Barnes, R.T.H., Hide, R., White A.A. and Wilson, C.A., 1983: Atmospheric angular momentum fluctuations, length-of-day changes and polar motion, *Proc. R. Soc. Lond.*, **A 387**, 31-73.

Quarterly report on numerical products from Bracknell - U.K. Meteorological Office, London.

AAM(UKMO) 83 * 01 From 1983 to 1994

Year	Number of meas.	Year	Number of meas.
1983	241	1991	679
1984	366	1992	713
1985	365	1993	728
1986	306	1994	717
1987	721		
1988	725		
1989	727		
1990	721		

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Dépôt légal 3ème trimestre 1995