IERS TECHNICAL NOTE 17

Earth orientation, reference frames and atmospheric excitation functions submitted for the 1993 IERS Annual report

VLBI, LLR, GPS, SLR and AAM Analysis Centres

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September 1994

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1993 IERS ANNUAL REPORT

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Filename		Contents
bulletinb.NN	:	Earth orientation parameters (x,y,UT,dPsi,dEpsi)
bulletinc.NN	:	Announcement of the leap seconds in UTC.
bulletind.NN	:	Announcement of the value of DUT1 to be transmitted with time signals. NN is the number of the issue.
eopc01.dat	:	Normal values of EOP at 0.05 year intervals.
eopc02.YY	:	Normal values of EOP at 5-day intervals.
eopc03.YY	:	Normal values of UT at 1-day intervals.
eopc04.YY	:	Smoothed values of EOP at 1-day intervals. YY is the year-1900.
icrf93.rsc	:	Radio Source Coordinates (1993 IERS Annual Report)
icrf93.car	:	Characteristics of radio Source (1993 IERS Annual Report)
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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 1 : C. Boucher and Z.Altamimi. The initial IERS Terrestrial Reference Frame.

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 6 : C. Boucher and Z. Altamimi. ITRF89 and other realizations of the IERS Terrestrial Reference System for 1989.

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

No 9 : C. Boucher and Z. Altamimi. ITRF90 and other realizations of the IERS Terrestrial Reference System for 1990.

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

No 12: C. Boucher and Z. Altamimi. ITRF91 and other realizations of the IERS Terrestrial Reference System for 1991.

No 13: D.D. McCarthy (ed.). IERS Standards (1992).

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 Earth orientation, reference frames and atmospheric excitation functions submitted for the 1992 IERS Annual Report.*[Superseded by T.N. 17]*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.

Future issue

No 18: C. Boucher, Z. Altamimi and L. Duhem. ITRF93 and its associated velocity field

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VERY LONG BASELINE INTERFEROMETRY

EARTH ORIENTATION PARAMETERS FROM IRIS-S VLBI MEASUREMENTS

GIUB 94 R 01

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Since 1990 the VLBI group at the Geodetic Institute of the University of Bonn (GIUB) has regularly correlated and analysed VLBI experiments which are observed once per month under the acronym IRIS-S (International Radio Interferometric Surveying - South). Until now 71 experiments have been 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. Since early 1986 when HartRAO was first equipped with a hydrogen maser frequency standard and a Mark III data acquisition terminal the IRIS-S network has been scheduled to observe for two months each year in the beginning and regularly in monthly intervals from late 1989. The network first consisted of the stations Wettzell, HartRAO, Westford and Richmond with Onsala and Fort Davis participating in a few experiments (Carter *et al.*, 1988). In the meantime, several changes were necessary: Mojave replaced Fort Davis and was closed eventually, Santiago (Chile) was excluded again after 10 months of participation for financial reasons and Fortaleza (Brazil) started operation in July 1993. Today the network is formed by the stations of Wettzell, HartRAO, Westford and Fortaleza.

In recent months the field of data analysis activities at the Geodetic Institute has been extended to the data gathered with the new German station O'Higgins in Antarctica (Hase and Nothnagel, 1993). So far the station of O'Higgings has successfully observed two bursts of five experiments each with networks consisting of the stations of Santiago (Chile), Hobart (Tasmania, Australia), DSS45 (NASA Complex of TidLinbilla, Australia) and HartRAO. The first burst was observed in January/February 1993 while the second burst took place in September 1993 with three experiments being available to date. These experiments contribute a number of precise source positions in the deep south.

The IRIS-S and the O'Higgins sessions are analysed using the CALC 7.6/SOLVE/GLOBL software system (Caprette *et al.*, 1990) which is based on the IERS 1989 Standards (McCarthy (ed.) *et al.*, 1989) and which is consistent with the IAU (1976) Resolution on Astronomical Constants, Time Scales and the Fundamental Reference Frame (Kaplan, 1981). The theoretical delays in the adjustment are calculated according to the Shapiro model (Ryan, 1989) and Hellings (1986) correction for relativistic bending. Horizontal and vertical ocean loading displacement effects of Scherneck (1991) are applied to the delay observables.

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 in polar motion and UT1. The corrections are modelled using the Wünsch and Busshoff (1992) amplitudes for UT1 and the Brosche and Wünsch (1994) amplitudes for polar motion (both scaled by 1.13 to subtract the equatorial moment of inertia of the core):

UT1 tidal terms

l	l'	F	D	Om	GST +π	Tide	A1 Amplitude [μs]	A2 Amplitude [μs]
0	0	0	0	0	-1	K1	14.64	11.48
0	0	2	-2	2	-1	P1	-6.09	-5.91
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 [μs]	A2 Amplitude [μs]
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	0	-2	0	-2	1	O1 p	-177.89	38.46
0	0	2	-2	2	-2	S2 r	-64.02	227.65
0	0	2	0	2	-2	M2 r	164.97	258.94
1	0	2	0	2	-2	N2 r	15.66	35.95
0	0	-2	2	-2	2	S2 p	-11.65	-29.45
0	0	-2	0	-2	2	M2 p	26.88	-103.40
-1	0	-2	0	-2	2	N2 p	12.32	-18.26

p = prograde, r = retrograde

The observations are individually calibrated for ionospheric refraction effects applying delay differences of dual frequency observations. The hydrostatic component of atmospheric refraction is calibrated using the MTT model (Herring, 1992) based on surface meteorological data while the wet component is estimated with a 3-hour piecewise-linear function where surface meteorological data is available. Only if station logs indicate a rapidly changing climatic environment or surface meteorological data is not available shorter intervals are chosen. The station clocks are generally modelled with second order polynomials and only where the residuals show an abnormal behaviour a small number of additional clock parameters is introduced. A smaller number of clock parameters as compared to a stochastic treatment of the clocks is chosen in order not to weaken diurnal and sub-diurnal signals in the Earth orientation parameters. Only delay observables are used and no restrictions are applied to the data in terms of elevation limits which are set to 7 degrees during preparation of the observing schedules.

In a combined solution (GIUB 94 R 01) all IRIS-S measurements since January 19, 1987, and eight experiments of the O'Higgins bursts have been 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. The origin of the terrestrial reference frame is fixed through the Wettzell station coordinates which are kept at the ITRF 1992 (Boucher *et al.*, 1993) values applying drift effect corrections according to the NNR-NUVEL-1 model (Argus and Gordon, 1991). The station coordinates of all other stations are estimated. The experiment observed on December 21, 1989 is used as a reference for the determination of the Earth orientation parameters, i.e. pole components and UT1 are fixed at the USNO Rapid Service values (IERS Bulletin A) and the nutation angles are calculated according to the IAU 1980 nutation theory (Wahr, 1981). For each of all other experiments one set of Earth orientation parameters consisting of two pole components, UT1-UTC, and two offsets relative to the IAU nutation theory are estimated. The reference epochs for UT1-UTC and polar motion are the midnight epochs of each measurement period while the nutation offsets are estimated at the beginning of each experiment. The values quoted represent EOPs smoothed over 24 hours and thus do not include diurnal and subdiurnal contributions for the specific epochs.

In respect to the continental drift history the participating stations are divided into three groups. O'Higgins, Santiago, DSS45, Hobart and Fortaleza have contributed data to the two projects which span too short periods to detect any significant motion. Wettzell, Westford and Richmond have shown relative drifts which agree with the NNR-NUVEL-1 model to within 1 mm in the north and east components while HartRAO and Mojave disagree at a 6 to 8mm/year level (Ryan *et al.*, 1993). Taking these peculiarities into account the motions of the stations are parametrized as follows: In the absence of a truly global distribution of stations the motion of the Wettzell - Westford - Richmond triangle is modelled according to NNR-NUVEL-1 defining the long term orientation of the network. Horizontal drift components are estimated for HartRAO and Mojave. Vertical drifts for these stations are constrained to zero since the network and the duration of the series are not considered sufficient for a reliable estimation of height variations at these stations. All other stations with only a short history are also supposed to move according to NNR-NUVEL-1.

The origin of right ascension is fixed by the ICRF 1992 position of OJ287 (IERS, 1993). The one-sigma formal errors of the parameters are based on observation weights which are adjusted so that the Chi-square per degree of freedom ratio per baseline is close to unity.

References

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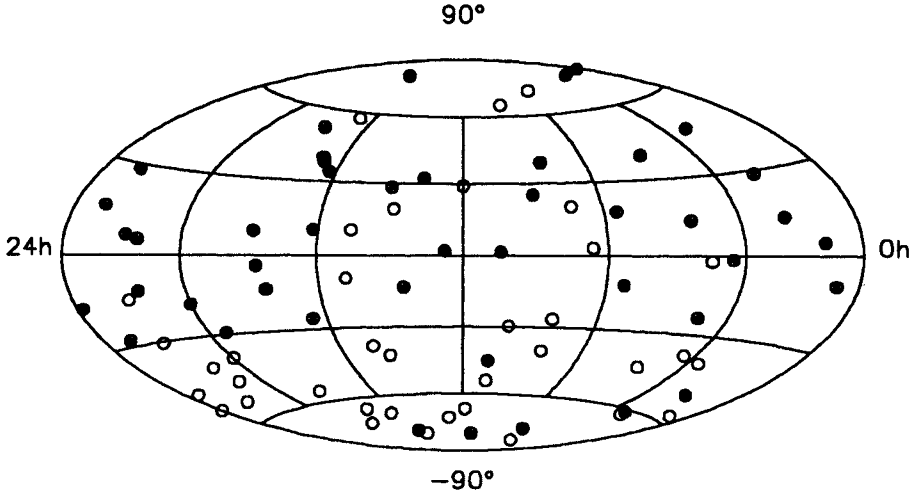
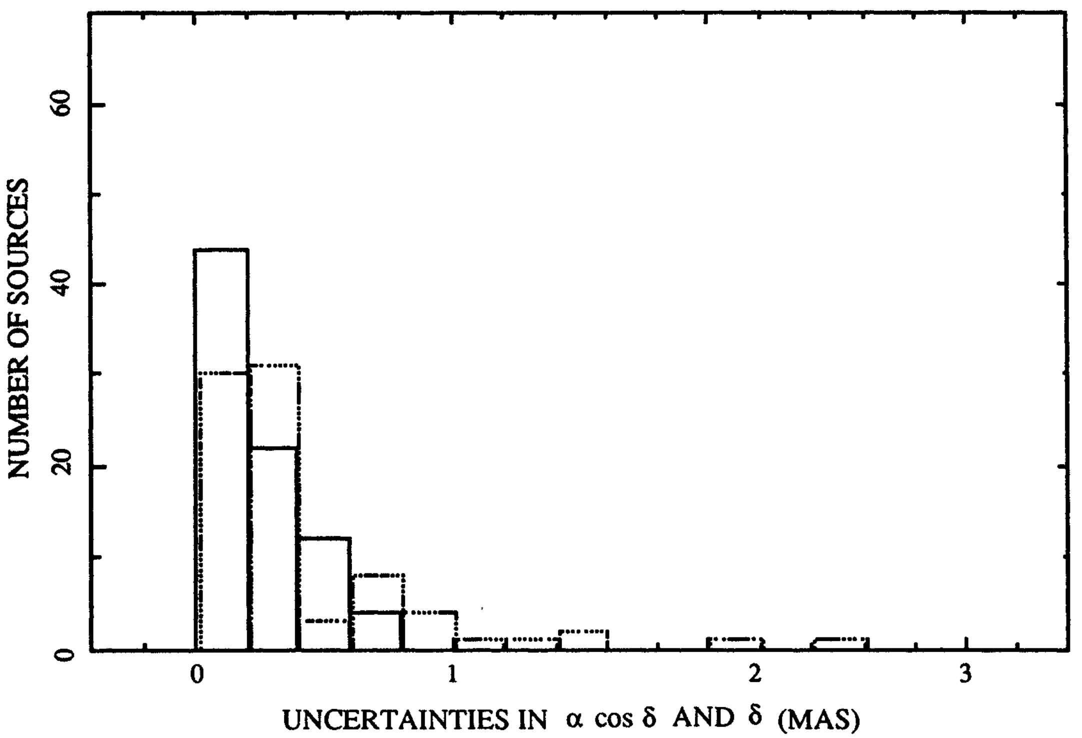
Summary description of solution GIUB 94 R 01

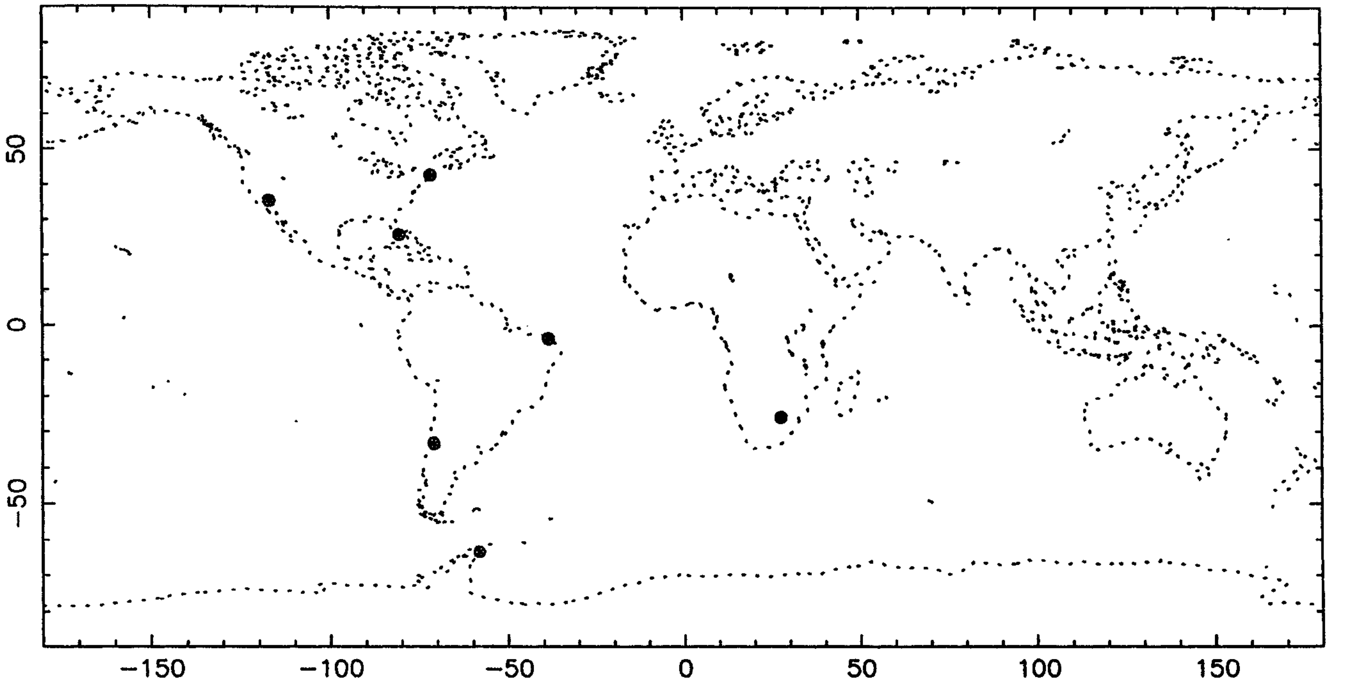
1 - Technique:		Mark III VLBI, Group delay observables
2 - Analysis Center:		Geodetic Institute of the University of Bonn, Nussallee 17, D-53115 Bonn, Germany
3 - Solution identifier:		GIUB 94 R 01
4 - Software used:		CALC 7.6, SOLVE/GLOBL
5 - Relativity scale:		Solar System Barycenter
6 - Permanent tidal correction on station:		Not applied
7 - Tectonic plate model:		NUVEL-1 NNR
8 - Velocity of light:		2.99792458 10^8 m/s
9 - Geogravitational constant:		Not applicable
10 - Reference epoch:		1989 Dec. 21 for Earth orientation and nutation 1988 Jan. 01 for site coordinates J2000.0 for radio source positions
11 - Adjusted parameters:		clock polynomials, wet troposphere parameters, EOP, celestial pole offsets, station coordinates, horizontal velocities of HartRAO and Mojave, radio source positions
12 - Definition of origin:	Terrestrial:	Fixing Wettzell ITRF 1992 coordinates
	Celestial:	Fixing OJ287 ICRF 1992 right ascension
13 - Definition of orientation:		Fixing USNO concrete EOP series and IAU 1980 Nutation for 1989 Dec. 21
14 - Evolution in time:		Velocities estimated for Mojave and HartRAO, all other stations move according to NUVEL-1 NNR



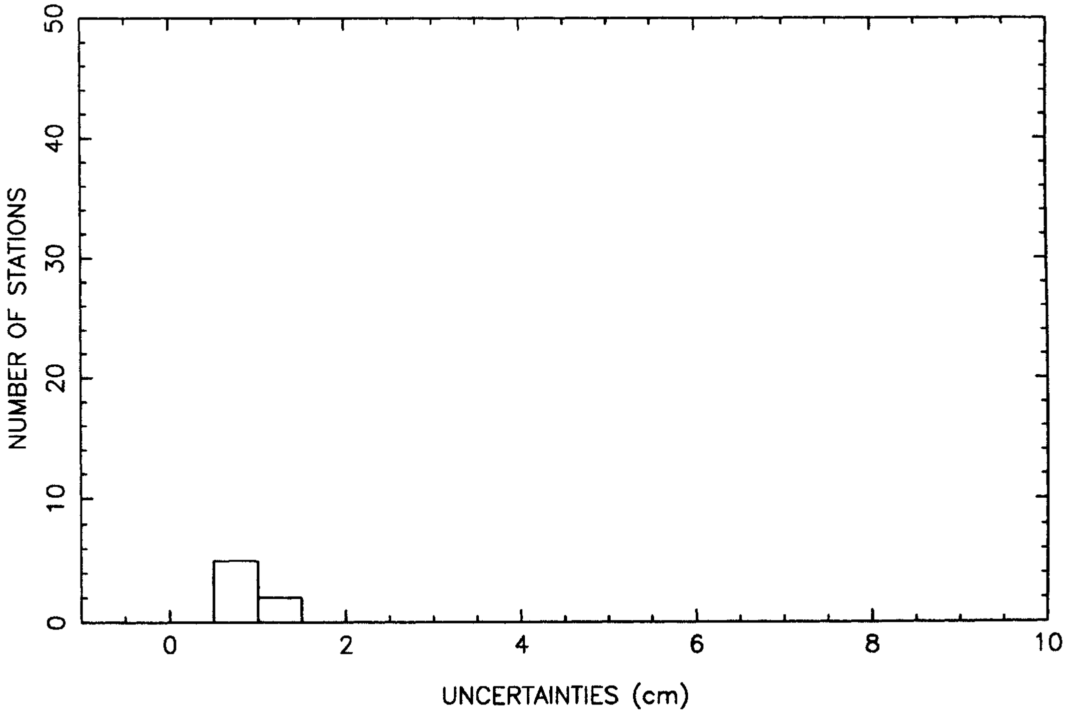
Distribution over the sky of the 83 extragalactic radio sources of the celestial frame RSC(GIUB) 94 R 01. Filled circles indicate radio sources with uncertainties in right ascension (α cos δ) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(GIUB) 94 R 01. 2 radio sources with uncertainties larger than 0.003" are not shown.



Distribution of the 7 sites of the terrestrial frame SSC(GIUB) 94 R 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 7 stations of the terrestrial frame SSC(GIUB) 94 R 01.

EOP(GIUB) 94 R 01 From Jan 1987 to Dec 1993

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
1987	8	0.47	8	0.33	8	0.36	8	0.52	8	0.23
1988	4	0.41	4	0.30	4	0.47	4	0.53	4	0.25
1989	6	0.45	6	0.32	6	0.27	6	0.61	6	0.30
1990	11	0.36	11	0.26	11	0.19	11	0.50	11	0.24
1991	12	0.34	12	0.26	12	0.18	12	0.47	12	0.23
1992	12	0.35	12	0.27	12	0.19	12	0.45	12	0.21
1993	20	0.40	20	0.31	20	0.21	20	0.49	20	0.22

SITE POSITIONS AND VELOCITIES, SOURCE POSITIONS, AND EARTH ORIENTATION PARAMETERS FROM THE NASA SPACE GEODESY PROGRAM-GSFC: SOLUTION GLB932

GSFC 94 R 01

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Mark III VLBI delay and delay rate data acquired since 1979 by the NASA Crustal Dynamics Project, POLARIS/IRIS, the Geographical Survey Institute (Japan), the Communications Research Laboratory (Japan), the Naval Research Laboratory Reference Frame Program, the USNO NAVNET/NAVEX, and the NASA Space Geodesy Program-GSFC have been analyzed for the terrestrial and celestial reference frames. The sessions used for GLB932 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 for spacecraft navigation.

The combination of all data in a single solution and the constraints for the origin, translation, and rotation of the terrestrial reference frame (TRF) are the major changes from our previous submissions. A 10-cm correction to the vertical eccentricity measurement used for GORF7102 between 91/08 and 92/06 changes the position and velocity from the last submission.

The TRF origin is set close to that of ITRF92 by minimizing the station position adjustments at 1988.0 with respect to ITRF92 for nine stations (WESTFORD, RICHMOND, GILCREEK, KAUAI, HOBART26, DSS45, HARTRAO, WETTZELL, and ONSALA60). The translational and rotational defects of the TRF are removed by minimizing the horizontal velocity adjustments of eight stations with respect to NUVEL-1 NNR (Argus and Gordon, 1991) and by minimizing their vertical rate adjustment. The stations (WESTFORD, RICHMOND, GILCREEK, KAUAI, HOBART26, DSS45, WETTZELL, and ONSALA60) are chosen for their global distribution, strong data, location in relatively stable parts of their respective plates, and absence of large deviations from the NUVEL-1 model. While this type of constraint removes the singularity present in the WESTFORD-RICHMOND-KAUAI constraint used in previous GSFC submissions, it distributes the discrepancies in relative motion from NUVEL-1 into individual site velocities in a manner that may be more difficult to interpret. The orientation of the terrestrial and celestial reference frames is defined by EOP and nutation offset values from the one-day EOP(IERS) 90 C04 series modified to match ITRF92 (M. Feissel, personal communication) and the standard J2000.0 precession and IAU 1980 nutation models for the EOP reference date 1993 Sep. 30. The right ascension origin is defined by the ICRF92 value for 2145+067.

In general, the three-dimensional velocities of sites with sufficient data were estimated. Those sites whose vertical rates had formal errors in excess of 3 mm/yr in an unconstrained solution were constrained to have zero vertical rate in this solution. The positions of seven sites (YAKATAGA, SOURDOGH, WHTHORSE, FORTORDS, PRESIDIO, MOJAVE12, and DSS15) each had one discontinuous change in position related to seismic events, and one site (NRAO85_3) had a discontinuous change for unknown causes. The velocities of some sites (FORT_ORD-FORTORDS, KASHIMA-KASHIM34, DSS65-ROBLED32, KAUAI-HALEAKAL-KOKEE-MK-VLBA, MOJAVE12-MOJ_7288, OVRO_130-OVR_7853-OV-VLBA, SESHAN25-SHANGHAI, NRAO 140-NRAO85_1, HRAS 085-FTD_7900-MCD_7850-FD-VLBA, ONSALA60-MV2ONSLA, YELLOWKN-YLOW7296, GORF7102-GGAO7108) were constrained to be equal in order to strengthen the position or velocity estimates or to propagate more correctly the position of a site occupied only once.

About 180 sources used in the geodetic programs form the core of the celestial reference frame. These have ~100 to ~90000 observations each. About 390 sources have formal errors under 1 mas. The remaining sources include a number with weak data. Sources with uncertainties >10 mas are not reported.

Instantaneous EOP values and UT1 rates were estimated at the middle of each observing session. No tidal terms in UT1 have been removed from the tabulated values of UT1-UTC. The pole and UT1 values include modeled diurnal and semidiurnal tidal variations.

All uncertainties are 1-sigma formal standard errors from the sequential least-squares solution GLB932 described below.

The basic models used to calculate the VLBI delays are generally consistent with the 1992 IERS standards and are contained in the Goddard CALC 7.6 program. These include IAU 1980 nutation with daily offsets in longitude and obliquity estimated, solid earth tides ($h2 = 0.60967$, $l2 = 0.085$) 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 dry troposphere effect was modeled from local meteorological data using the Saastamoinen zenith delay and the MTT dry troposphere mapping (Herring, 1992), while the residual wet troposphere was estimated using a continuous, piecewise-linear function with the MTT wet model (Herring, 1992). The behavior of the site clocks for each day was similarly estimated using a quadratic polynomial and a continuous, piecewise-linear function. For both estimates the variation in the continuous function was constrained to physically reasonable values except in the rare instances when the data dictated otherwise. For each session a single reweighting constant computed for the particular day was added in quadrature to the data uncertainties derived strictly from SNR to reflect the actual data scatter.

The GLB932 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 (1903 sessions, 1112475 delays, 40256 delay rates) 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 data (291 sessions, 106101 delays, 2427 delay rates), largely mobile and small network sessions. Finally the reported EOP and nutation offset values were generated from a back solution, again using the modified EOP(IERS) 90 C 04 series as a priori values and weak EOP constraints. While EOP values are given for all sessions, a flag indicates which values are useful.

In total 1218576 dual-frequency Mark III delays and 42683 delay rates from 2194 sessions were included. Only delay rate data from astrometric and survey sessions were included. The least-squares solution had 1799 global parameters and 434611 arc parameters with 974918.3 degrees of freedom. The weighted rms post-fit delay residual of the solution was 38.4 ps in delay and 77.9 fs/s in delay rate. The reduced chi-square was 1.029 including the constraints for the wet troposphere, clocks, and EOP in the computation of the degrees of freedom (Theil, 1963).

The site coordinates and velocities at 1988.0 are designated SSC(GSFC) 94 R 01. Other results are the Earth orientation time series designated EOP(GSFC) 94 R 01 and source positions designated RSC(GSFC)94 R 01.

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Herring, T. A., 1992: *Proceedings of the Symposium on Refraction of Transatmospheric Signals in Geodesy, Publications on Geodesy*, No. **36**, ed. by De Munck, J.C. and T. A. Th. Spoelstra, Netherland Geodetic Commission, Delft, Netherlands, p. 247.

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Summary description of solution GSFC 94 R 01

1) Technique: Mark III VLBI

Processed with the Mark-III Analysis System - CALC/GLOBL with the following:

- Group delay observations used for geodetic data, group delays and phase delay rates used for astrometric data.

- 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) that are consistent with those of Herring, Sovers and Watkins. The model below was applied in this solution.

UT1 tidal terms (microseconds)

l	l'	F	D	Om	GST +π	term	Cos	Sin
0	0	0	0	0	-1	K1	7.486602	16.707637
0	0	2	-2	2	-1	P1	-3.500205	-5.392255
0	0	2	0	2	-1	O1	-15.575852	-16.762598
1	0	2	0	2	-1	Q1	-3.394904	-3.902930
0	1	0	0	0	-1	S1	593333	1.932245
1	0	0	0	0	-1	M1	1.003345	1.299982
0	0	0	0	0	-2	K2	261715	3.896805
0	0	2	-2	2	-2	S2	-1.182862	8.706599
0	0	2	0	2	-2	M2	-8.517385	12.338927
1	0	2	0	2	-2	N2	-4.378455	1.168543

Polar motion tidal terms (microarcseconds)

l	l'	F	D	Om	GST +π	term	Cos	Sin
0	0	0	0	0	1	P K1	125.285183	-38.476327
0	0	-2	2	-2	1	P P1	-54.470359	26.152833
0	0	-2	0	-2	1	P O1	-136.319298	63.668538
-1	0	-2	0	-2	1	P Q1	-33.990240	18.096315
0	0	0	0	0	-2	R K2	-15.899321	15.676795
0	0	2	-2	2	-2	R S2	-76.296961	105.813157
0	0	2	0	2	-2	R M2	15.018756	285.140733
1	0	2	0	2	-2	R N2	-24.572257	58.610024
0	0	0	0	0	2	P K2	22.589310	-5.801947
0	0	-2	2	-2	2	P S2	-7.259654	-11.309321
0	0	-2	0	-2	2	P M2	30.337902	-72.186765
-1	0	-2	0	-2	2	P N2	-11.643736	-30.168262

P = Prograde, R = Retrograde

- Instantaneous EOP and UT1 rate estimated at midpoint of observing sessions.

- A priori calibration of the 'dry' atmosphere via MTT dry mapping with either in situ measurements of pressure and temperature or site-dependent static values and the Saastamoinen zenith delay.

- No a priori calibration of the 'wet' atmosphere.

- Residual wet atmosphere estimated with the GSFC 'continuous piecewise-linear function' technique with 60 minute intervals and 50 ps/hour constraint (except for a small subset of sessions using either shorter intervals or looser constraints) and the wet MTT partial derivative.

- Hydrogen maser clock errors modeled with the GSFC 'continuous piecewise-linear function' method using unconstrained 2nd order polynomials for the gross clock performance and continuous 60-minute interval segments with a clock rate constraint of 5.10^{-14} for the short term clock errors (except for a small subset of sessions using either shorter intervals or weaker constraints); a small number of actual clock epoch breaks and baseline-dependent constant clock errors also modeled.

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

- Data to SHANGHAI (7226), VLA (7619), and USSURISK (7247) lack ionosphere calibration. The USSURISK vertical position is not considered reliable since the adjustment of the axis offset gives a value of several meters.

- Solution in several steps to apply VLBI EOP information to some sessions.

2) - Analysis Center:
GSFC - the VLBI group of the NASA Space Geodesy Program at the Goddard Space Flight Center.

3) - Solution Identifier:
GLB932

4) - Software used:
CALC 7.6, SOLVE/GLOBL, and DE200 ephemerides.

5) - Relativity Scale:
Set by the modified Hellings VLBI delay model described in the CALC 7 release documentation.

6) - Permanent tidal correction on station:
A solid earth tide model is used but the correction to remove the permanent tide (specified the IERS Standards) is not applied.

7) - Tectonic plate model:
No-Net-Rotation NUVEL-1 in all solutions.

8) - Velocity of light:
2.99792458 10^8 m/s

9) - Geogravitational constant:
Not applicable.

10) - Reference epoch:
1993 September 30 for both earth rotation and nutation, 1988 January 1 for site positions. Source coordinates are J2000.0.

11) - Adjusted parameters:
X/Y pole, UT1, dUT1/dt, daily nutation offsets, global station positions and velocities, global source positions except the right ascension of 2145+067, and session-dependent clock and atmosphere parameters.

12) - Definition of the 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.

13) - Definition of the 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). The celestial reference frame is defined by the CEP pole position computed from the IAU 1980 nutation model and the J2000.0 precession model for the same reference day corrected by the nutation offsets from the modified EOP(IERS) 90 C 04 series and by the ICRF92 right ascension of 2145+067.

14) - Evolution with time:
The horizontal rate residuals of eight stations (WESTFORD, RICHMOND, GILCREEK, KAUAI, HOBART26, DSS45, WETTZELL, ONSALA60) with respect to No-Net-Rotation NUVEL-1 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-NUVEL-1 with uncertainties in vertical, east and north rates of 0, 3, and 3 mm/yr, respectively. These stations are:

SEST	OCOTILLO	VICTORIA	FORTLEZA	OHIGGINS	BR-VLBA
TITIJIMA	MIYAZAKI	MIZNAO10	CHLBOLTN	USSURISK	HN-VLBA
VLA	MIZUSGSI	SAGARA	AUSTINTX	CARROLGA	BERMUDA
SINTOTU	USUDA64	MILESMON	BLOOMIND	LEONRDOK	SC-VLBA
BREST	CARNUSTY	METSHOVI	HOHENFRG	GRASSE	HOFN
KARLBURG	TOULOUSE	AZORES	HOHNBERG	KIRSBERG	

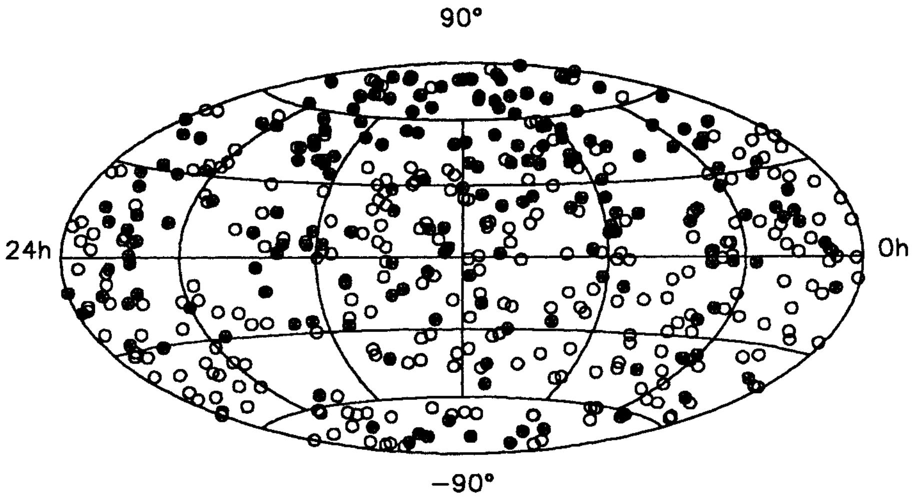
The vertical rates for stations that had uncertainties in their vertical rates in excess of 3mm/yr in an unconstrained solution are also constrained to zero with the exception of YELLOWKN/YLOW7296. These stations are:

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

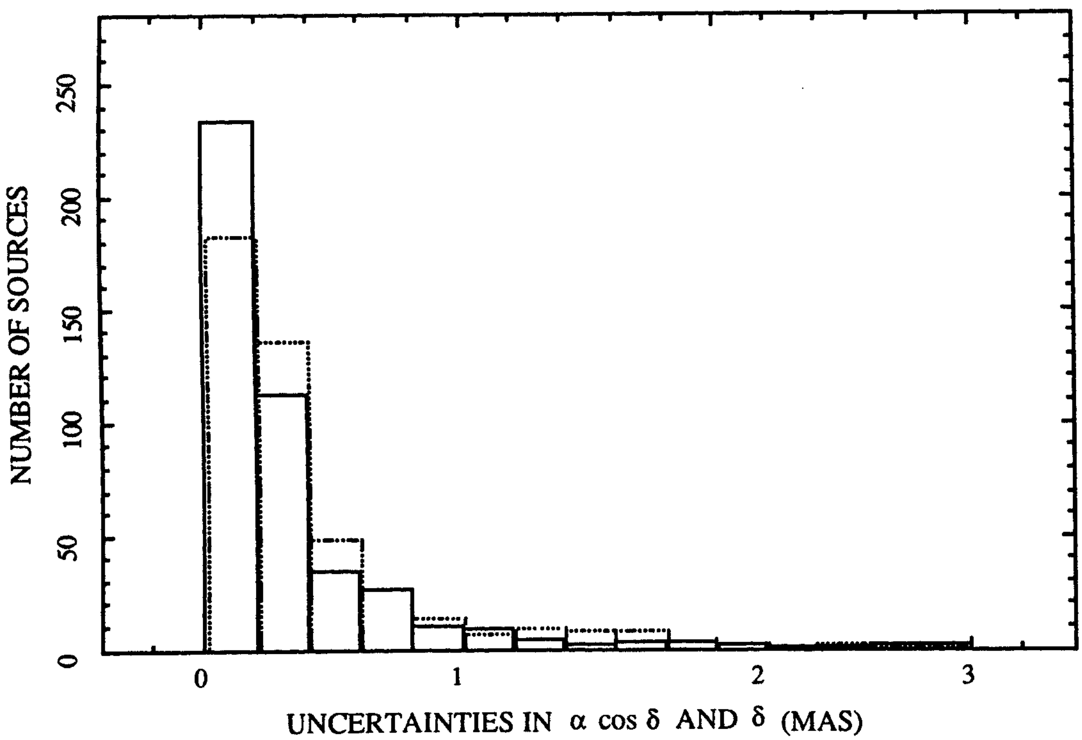
EOP(GSFC) 94 R 01 From Aug 1979 to Dec 1993

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

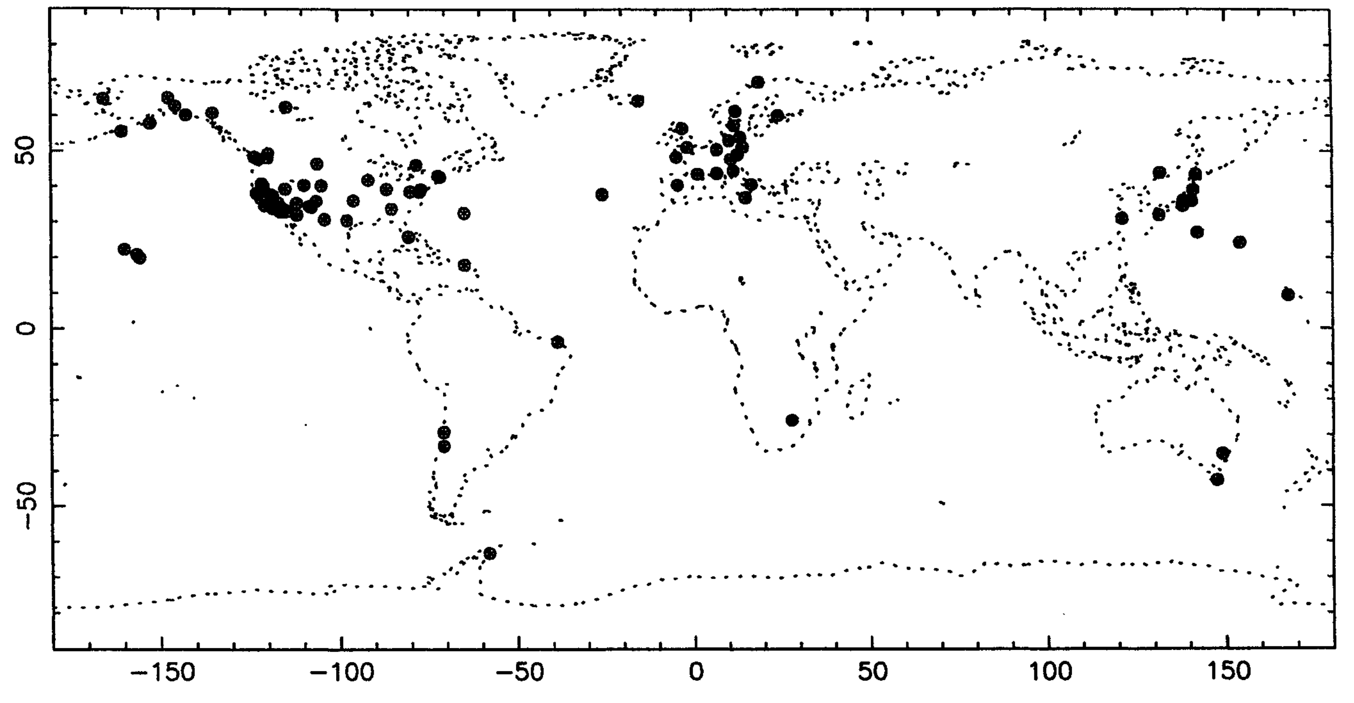
YEAR	X		Y		UT1		$\delta\psi$		$\delta\epsilon$	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
1979	2	1.17	2	2.28	2	0.84	2	1.87	2	0.67
1980	20	0.61	20	0.62	20	0.30	20	0.98	20	0.43
1981	34	12.75	34	40.55	34	10.32	34	3.21	34	1.14
1982	62	12.74	62	40.55	62	10.32	62	2.89	62	1.11
1983	85	12.67	85	33.24	85	10.23	85	2.27	85	0.94
1984	119	0.76	119	0.69	119	0.37	119	1.10	119	0.43
1985	130	0.47	130	0.45	130	0.24	130	0.73	130	0.27
1986	152	0.47	152	0.42	152	0.24	152	0.71	152	0.25
1987	184	0.47	184	0.43	184	0.24	184	0.71	184	0.26
1988	208	0.46	208	0.45	208	0.26	208	0.64	208	0.25
1989	247	0.35	247	0.36	247	0.19	247	0.55	247	0.22
1990	268	0.26	268	0.27	268	0.14	266	0.44	266	0.18
1991	244	0.21	244	0.22	244	0.12	241	0.37	243	0.15
1992	254	0.20	254	0.20	254	0.09	253	0.34	253	0.15
1993	185	0.16	185	0.14	185	0.07	184	0.26	184	0.11



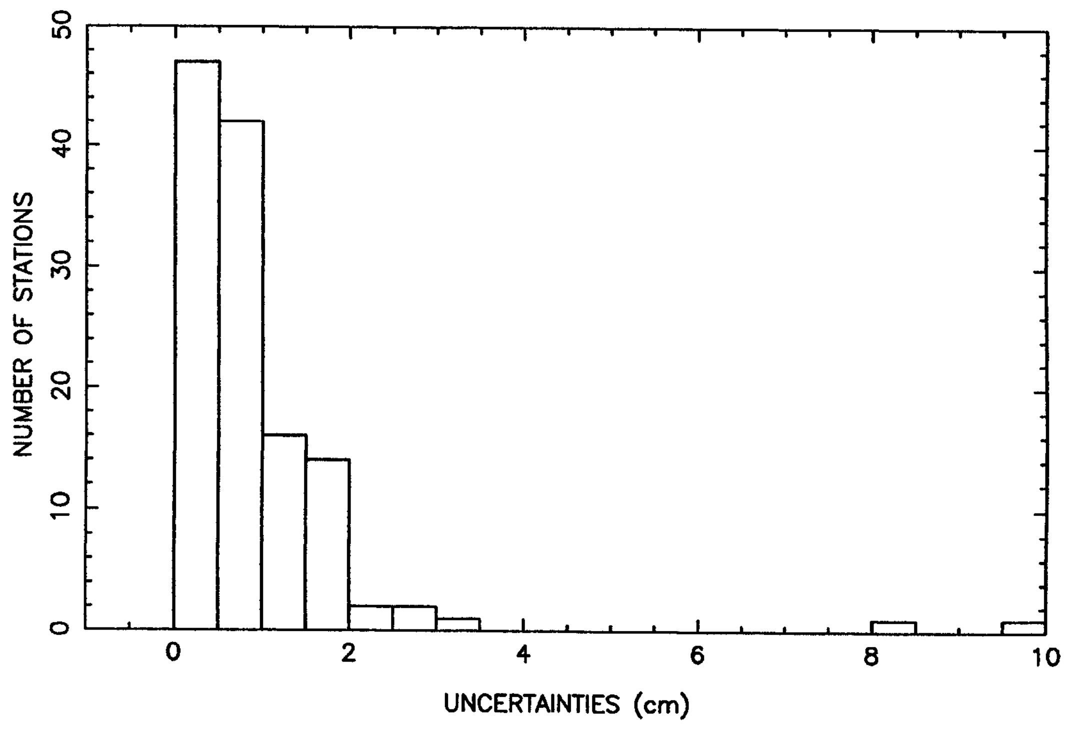
Distribution over the sky of the 469 extragalactic radio sources of the celestial frame RSC(GSFC) 94 R 01. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(GSFC) 94 R 01. 24 radio sources with uncertainties larger than 0.003" are not shown.



Distribution of the 99 sites of the terrestrial frame SSC(GSFC) 94 R 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 127 stations of the terrestrial frame SSC(GSFC) 94 R 01. 1 station with uncertainly langer than 10 cm is not shown.

EARTH ROTATION PARAMETERS FROM DSN VLBI: 1994

JPL 94 R 01

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The main changes in this year's report from last year's report are evolutionary, due to the acquisition of another year's data.

In this report Earth Rotation Parameter (ERP) estimates have been obtained from an analysis of Deep Space Network (DSN) VLBI data that directly aligns its celestial and terrestrial reference frames with those of the International Earth Rotation Service (IERS). NASA's Deep Space Network operates radio telescopes for the primary purpose of communicating with interplanetary spacecraft. The DSN has three complexes: in California (stations DSS 12,13,14,15), in Spain (DSS 61,63,65), and in Australia (DSS 42,43,45). Two projects at JPL (called TEMPO and CAT M&E below) use these telescopes to make VLBI observations from which we have estimated earth rotation parameters. Most observing sessions use antennas in only two complexes, and usually exactly one antenna in each complex. This report describes a homogeneous reduction of currently available dual frequency (S and X band) VLBI data from both projects.

The Time and Earth Motion Precision Observations (TEMPO) project makes rapid turnaround VLBI measurements of station clock synchronization and earth orientation in support of spacecraft navigation, which needs extremely timely, moderate accuracy earth rotation information. In TEMPO observations the raw bit streams recorded at the telescopes are telemetered to JPL for correlation, so that no physical transportation of magnetic tapes is involved. TEMPO uses the JPL-developed Block I VLBI system, which has a 500,000 bits/second sampling rate, with time-division multiplexing of channels. This sampling rate permits the telemetry, and thus makes rapid turnaround possible. The reduced sensitivity caused by the relatively low sampling rate in comparison to other present-day VLBI systems is largely compensated by the very large antennas and very low system noise levels of the DSN telescopes. TEMPO uses two 70 meter DSN antennas (DSS 14, 43, 63) whenever possible and one 34 meter DSN antenna together with one 70 meter antenna when it is not possible to obtain simultaneous use of both of the larger antennas. Currently, TEMPO records 3 channels in S band (2285 MHz) and 3 channels in X band (8450 MHz). Since June 12, 1991, TEMPO has used a spanned bandwidth of 99 MHz at X band and 39 MHz at S band. Before that date, most TEMPO sessions used a spanned bandwidth of 40 MHz in each band. At present the DSN nominally schedules two TEMPO observing sessions per week, one on the Spain-California (SC) baseline, and the other on the Australia-California (AC) baseline. Each session is generally 3 hours in duration (occasionally less), and records a maximum of 20 sources. TEMPO observes most sources for 3 minutes and 18 seconds, a few for 6 minutes and 36 seconds. We plan to produce an operational series of ERP estimates from TEMPO sessions during 1994 that will be a continuation of the ERP series reported here.

The Catalog Maintenance and Enhancement (CAT M&E) project determines celestial coordinates of radio sources, and baseline vectors between DSN stations, for use in spacecraft navigation. In CAT M&E observations the raw bit streams are recorded on magnetic tapes for transportation to the correlator. Since June 1989 most CAT M&E observing sessions have used the Mark III VLBI system on stations DSS 15, 45, and 65, which support a 400 MHz spanned bandwidth capability. From late 1978 through 1988, CAT M&E used the Mark II VLBI system with a spanned bandwidth of 40 MHz in each band, and used two 70 meter DSN antennas (DSS 14, 43, 63) whenever possible. The DSN schedules CAT M&E observing sessions at irregular intervals, typically several times per year, with separate observing sessions on the SC and AC baselines. Each session is nominally 24 hours in duration and typically includes 100 to 330 observations of 50 to 134 radio sources.

Data from both the TEMPO and CAT M&E projects were used in the solution process for the ERP series reported here. In order that the TEMPO operational series of ERP estimates during 1994 can be an exact continuation of the ERP series reported here, the solution process consisted of two major steps. First, a "catalog solution" designated JPL 1994-1 (see below) determined radio source coordinates, station coordinates and site velocities, a parametric model for the celestial motion of the Celestial Ephemeris Pole, and a parametric model for the nearly-diurnal and nearly-semidiurnal tidal frequency variations of UT1 and polar motion. Then the second step, called the "ERP solution", used these results from the catalog solution to determine the earth rotation parameters in a manner that can be exactly continued in the operational series. In the ERP solution the data from each observing session were processed independently to provide an estimate of the UT0 and variation of latitude (DPHI) of the baseline VECTOR for that session. Except for the UT0 and variation of latitude, the relation between the earth-fixed reference frame and the radio-quasar reference frame was specified entirely by a priori data (which includes the results from the catalog solution). In addition to UT0 and DPHI, the other parameters estimated in the ERP solution were:

1 - A first degree polynomial clock model, including a term allowing for a bias in the phase-delay-rate data, with breaks as needed.

2 - Adjustments to the troposphere zenith delay at each station. In the CAT M&E sessions, new troposphere zenith parameters were introduced approximately every three hours (every two hours for data after 1992.0). A priori estimates of the troposphere zenith delays, derived from tables of monthly average zenith delays for each station, were included in the solution with a 6 cm standard deviation. (For good quality observing sessions in recent years, the effect of these a prioris is negligible and the estimated troposphere zenith delays are essentially completely determined by the VLBI observables.)

Other properties of the ERP solution were:

1 - The reported earth rotation parameters have had nearly-diurnal and nearly-semidiurnal tidal frequency variations removed according to the parametric model estimated in the catalog solution. (In other words, the

effects in the table below headed "Short Period Tidal ERP Variations" have NOT been added back in producing EOP(JPL)94 R 01.)

2 - Ocean loading effects were calculated from the model of Scherneck (1983; 1991).

3 - Pole tidal effects were included (Sovers, 1991).

4 - The Lanyi (1984) function was used for mapping zenith tropospheric delays to observed elevations.

5 - The effects of charged particles in the ionosphere and solar plasma on the single-band delay and delay rate observables were removed by using the appropriate linear combination of the S-band and X-band data to form "dual frequency" delay and delay rate observables.

6 - For recent years only sessions with 6 or more acceptable delay observations were included in the solution reported here.

7 - The effect on path lengths caused by moving ("slewing") the antenna subreflector, so as to maximize the antenna gain when its focal length changes as the elevation angle changes, has been modeled for the TEMPO data. No such model is needed for the CAT M&E data since CAT M&E does not slew the subreflector. (Apparent station coordinates estimated from VLBI data will be corrupted if the subreflector is slewed but the effect on path length is not modeled in the delay calculations. The station coordinates estimated by the JPL 1994-1 catalog solution and used in the ERP solution are appropriate both for the case where the subreflector is not slewed and no path length effect is modeled and also for the case where the subreflector is slewed and the resulting effect on path length is explicitly modeled in the calculations.)

The raw observable uncertainties have been modified by adding quadratically an uncertainty component, for each of the two stations, equal to a small fraction (0.002 or 0.003) of the total a priori tropospheric effect at that station on the observable. We further quadratically added an "additive noise" constant when needed so as 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.

Each Earth Rotation measurement here is a UT0-DPHI pair, and has an associated error ellipse in the UT0-DPHI plane. Each such error ellipse is completely specified by the reported standard errors and correlation coefficient between UT0 and DPHI. For single baseline VLBI measurements of ERP, such as those reported here, this error ellipse is typically quite elongated, with a ratio of major axis to minor axis of about 4:1. Therefore, for a proper interpretation of these data, it is CRUCIAL to make full use of the reported correlation coefficient.

For a single-baseline VLBI estimate of earth rotation, the orientation of the error ellipse in the UT0-DPHI plane is mostly determined by the global station geometry. The direction of the minor axis of the error ellipse in the UT0-DPHI plane as predicted by the station geometry is called the transverse rotation direction, and corresponds to the motion of the baseline in the local horizontal at each station or equivalently to a rotation about an axis through the center of the earth and the midpoint of the baseline. In addition to being relatively insensitive to random measurement errors, the transverse rotation component is also relatively free of errors introduced by tropospheric modeling errors, antenna deformations, and other sources of systematic local-vertical errors. The transverse rotation components for the DSN baselines are:

Baseline	Transverse Component
Australia-California	-1.000 DPHI + 0.00 (UT0-TAI)
Spain-California	+0.582 DPHI + 12.21 (UT0-TAI)
Spain-Australia	-0.972 DPHI + 2.77 (UT0-TAI)

These coefficients assume that UT0 and DPHI are expressed in seconds of time and in arcseconds, respectively; the units of the transverse components are arcseconds. We recommend that these linear combinations be used to take full advantage of the inherent accuracy of these data.

The ERP solution produced earth orientation results for a total of 1042 observing sessions between October 28, 1978, and March 13, 1994.

During calendar year 1993, the TEMPO project produced earth rotation measurements from 93 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 1993 the median turnaround time for TEMPO measurements, from observation to availability of earth orientation parameters, was 49 hours.

The JPL 1994-1 Catalog

The JPL 1994-1 catalog was developed specifically for use in TEMPO operational ERP solutions during 1994. Since short duration VLBI determinations of the ERP are sensitive to errors in the celestial position of the Celestial Ephemeris Pole (CEP), and since the current IAU standards for the CEP are known to be in error by amounts significant to TEMPO, it is important that TEMPO use a CEP series that is corrected from the IAU standards and is consistent with the radio source coordinates (RSC) used. Current practicalities of TEMPO operations favor the use of a parametric model for the CEP that includes the long period motions. Therefore we have estimated such a model along with the RSC and set of station coordinates (SSC) in the JPL 1994-1 catalog solution. This year our CEP motion model consists of the ZMOA-1990-2 nutation model (Herring, 1991) plus adjustments to the coefficients of certain terms of the ZMOA-1990-2 model, along with the IAU precession model and adjustments to its coefficients. Our CEP motion model is intended only to permit processing of TEMPO data for the ERP during the period reported here and during 1994, and will presumably need revision in 1995. In particular, it may not include all significant components, not all its adjustments may be genuinely significant, and its parameters may not all be well separated, but we believe it is adequate for our purposes. As part of the JPL 1994-1 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 JPL 1994-1 catalog solution had the following properties:

1 - Except where otherwise noted, the catalog solution was essentially identical to the ERP solution described above.

2 - All the available CAT M&E data through December 19, 1993, and most of the TEMPO data through December 29, 1993, were included.

3 - Information from intra-complex radio interferometry was used to constrain the coordinate differences between stations within each complex. The uncertainties used for these intracomplex ties vary from station pair to station pair and from component to component (the local vertical uncertainty is typically three times the horizontal uncertainty). These uncertainties are our best estimates of the realistic one-standard-deviation uncertainties of these ties and range from 5 mm to 18 mm.

4. For each pair of observing sessions that used different pairs of DSN complexes (that is, California-to-Spain and California-to-Australia) with a time separation between the midpoints of the sessions of less than 15 hours, the adjustment (dX,dY,dUT1) to the initial values of earth orientation is the same for both members of the pair. (The initial-value ERP series was a version of the SPACE93 series (Gross, 1994) modified to not use DSN VLBI data; it is a smoothed, combination-of-techniques ERP series obtained by Kalman filtering). This treatment of close-in-time pairs serves to determine the angle between the California-to-Spain and California-to-Australia baseline vectors (and thus also the length of the Australia-to-Spain vector). There were 66 such pairs of TEMPO sessions; there were 7 such pairs involving one TEMPO session and one CAT M&E session; and there were no such pairs involving two CAT M&E observing sessions. This year there is one CAT M&E session (December 19, 1993) in which one station in each complex participated (DSS 15,45,65), with small groups of observations on the California-to-Spain and California-to-Australia baselines interleaved. Although the duration of this session was only 8 hours, it has significantly improved our knowledge of the rate of change of the length of the Australia-to-Spain vector. (A special thank you to Chris Jacobs for leading the effort to acquire this data, and for getting the results to us in time for this analysis).

5 - The terrestrial frame of the JPL 1994-1 system was tied to the International Earth Rotation Service Terrestrial Reference Frame ITRF-92

(IERS, 1993, Table T-3) in the following way. The coordinates of all the DSN stations, including all those in California, were estimated in the catalog solution subject to six constraints applied to the nine coordinates of DSS 15, DSS 45, and DSS 65. These constraints are such that if a seven parameter transformation (3 translations, 3 rotations, 1 scale) between the JPL 1994-1 and ITRF-92 systems were 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). These constraints serve to determine both the translation and the rotation of the terrestrial coordinate system. The station coordinates resulting from the solution apply at a reference time of 1988.0, in agreement with that of ITRF-92.

6 - 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-92 velocity field (IERS, 1993, Table T-5). Thus only three velocity parameters are actually being separately estimated; one way to describe these is as the rates of change of (1) the California-to-Australia length, (2) the California-to-Spain length, and (3) the angle between the California-to-Australia and California-to-Spain vectors. (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 - The celestial frame of the JPL 1994-1 system was tied to the International Earth Rotation Service Celestial Reference Frame in the following way. The Right Ascension and Declination of OJ 287 (0851+202) and the Declination of CTD 20 (0234+285), which are among the best observed sources in the DSN catalog and are primary sources in the 1993 realization of the IERS Celestial Reference Frame, were held fixed at their values in that frame as specified in the set of radio source coordinates RSC(IERS)93 C 01 (IERS, 1993, Table C-4). The formal errors of these three source coordinates are properly zero, but in order to convey the quality of determination of these two sources we have replaced these three zeros in our source list RSC(JPL)94 R 01 by the formal errors for these three coordinates from a similar solution that had three coordinates of two different well-observed sources held fixed; we have

similarly replaced the two correlation coefficients between Right Ascension and Declination for these two sources.

8 - The reference epoch of the JPL 1994-1 celestial system was J2000, and the definition of sidereal time was a function of the estimated precession constant (Sovers, 1991, sections 2.6.1 and 2.9.3.3).

This year we have used the MODEST option to perform the general relativity calculations according to the "TDT spatial coordinates" convention (Sovers, 1991). This choice has a small effect on the length scale of the Set of Station Coordinates. The relativity model used is essentially equivalent to the "consensus model" described by Eubanks (1991). As a result, the estimated Set of Station Coordinates has the scale of a geocentric coordinate system using a time scale consistent with International Atomic Time.

The parametric model for the nearly-diurnal and nearly-semidiurnal tidal frequency variations of UT1 and polar motion obtained as part of the JPL 1994-1 catalog solution is presented below. The argument conventions used here are those of Sovers *et al.* (1993). The formal errors of these parameters range from 13 to 53 microarcseconds but realistic uncertainties are probably about 75 microarcseconds (one standard deviation).

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	3.0	4.0	43	54	59	246
S2	12.00000	1.3	9.9	40	143	58	314
M2	12.42060	- 8.4	18.0	64	242	119	274
N2	12.65835	0.1	2.8	20	32	106	188
K1	23.93447	13.1	26.2	191	0	163	*
P1	24.06589	- 4.5	- 4.3	59	0	342	*
O1	25.81934	-13.3	-13.5	145	0	314	*
Q1	26.86836	3.6	- 1.8	38	0	323	*

The model of the celestial motion of the CEP obtained as part of the JPL 1994-1 catalog solution is presented below as adjustments to the IAU precession and ZMOA-1990-2 nutation coefficients along with two offset parameters which represent the estimated position of the (mean) CEP at epoch J2000 as expressed in the coordinate system of the radio sources. A positive X-offset represents a displacement of the CEP toward 18 hours Right Ascension, and a positive Y-offset represents a displacement of the CEP toward 0 hours Right Ascension. The CEP-motion model includes a term representing a secular rate in obliquity. Also included is an empirical term with a period of -429.8 days (for the origin of this particular value of period, see (Herring *et al.*, 1991; Herring, 1991)). Only those nutation terms listed below were adjusted in the catalog solution. Two sets of standard errors are presented; the "formal" errors are just the formal errors from the catalog solution, and the "generalized" errors are the formal errors from a similar solution which also estimated additional components with periods of 121.75, 27.55, 13.63, and 9.13 days as well as both out-of-phase nutations for all ten periods.

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	-3.21/yr	0.06/yr	0.14/yr
obliquity rate			Obliquity	-0.28/yr	0.05/yr	0.06/yr
Y-offset			L sin eps	-18.70	0.34	0.74
X-offset			Obliquity	+ 5.94	0.76	0.77
1	-6798.38	In	Longitude	- 0.98	0.31	0.73
			Obliquity	- 0.01	0.16	0.17
		Out	Longitude	+ 1.13	0.21	0.41
			Obliquity	- 0.15	0.29	0.29
2	-3399.19	In	Obliquity	- 0.23	0.08	0.08
		Out	Longitude	- 0.70	0.17	0.20
			Obliquity	+ 0.17	0.12	0.13
10	365.26	In	Longitude	- 0.50	0.08	0.10
			Obliquity	+ 0.03	0.03	0.03
		Out	Longitude	+ 0.64	0.08	0.09
			Obliquity	+ 0.00	0.03	0.04
9	182.62	In	Longitude	- 0.06	0.06	0.07
			Obliquity	- 0.04	0.02	0.03
		Out	Longitude	+ 0.18	0.06	0.07
			Obliquity	+ 0.01	0.02	0.03
31	13.66	In	Longitude	- 0.20	0.05	0.14
			Obliquity	+ 0.11	0.03	0.05
		Out	Longitude	+ 0.47	0.07	0.13
			Obliquity	+ 0.10	0.02	0.06
	-429.8	In	Longitude	- 0.04	0.08	0.09
			Obliquity	+ 0.02	0.04	0.04
		Out	Longitude	- 0.61	0.09	0.10
			Obliquity	- 0.12	0.03	0.03

For the 1994-1 catalog solution, the data set used has NOT been restricted to have only elevation angles above some arbitrary minimum value. Note however that low elevation observations are effectively down-weighted by the observable uncertainty adjustment procedure described above. Because the most frequently used stations in this data set (DSS 14,15,43,45,63,65) have antenna limits at 6.0 to 6.35 degrees elevation, almost all the data in this data set has elevation angles above 6 degrees. Because of the very long lengths of the DSN baselines, the DSN VLBI observing schedules have included low elevation observations since their inception. Since at least 1983, the TEMPO sessions have been designed to improve the determination of the troposphere zenith parameters and their separation from the geodetic parameters by deliberately including a few observations for this purpose, which have low elevation angles and are not near the cusps of the visibility sector. In the set of elevation angles associated with the observations included in the 1994-1 catalog solution, the portion that fall in each 10 degree increment is as follows (in percent):

0 - 10	- 20	- 30	- 40	- 50	- 60	- 70	- 80	- 90	degrees
8.8	23.8	21.5	17.5	13.9	9.0	3.0	1.9	0.7	percent

The average elevation angle is 30.70 degrees.

For accurate interpretation of the UT0 and DPHI values reported here, one should use accurate values of the latitude and longitude of the baseline vector; these can be calculated for each station pair from the SSC estimated in the JPL 1994-1 catalog solution and reported here. Approximate values are:

Baseline	Latitude (degrees)	Longitude (degrees)
Australia-California	- 43.97	+106.05
Spain-California	+ 2.99	+ 30.73
Spain-Australia	+ 38.50	- 18.10

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.

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

1 - Technique: VLBI

2 - Analysis Center: JPL

3 - Solution identifier: 1994-1

4 - Software used: MODEST (nee Masterfit)

5 - Relativity scale: LE (TDT = geocentric with IAT)

6 - Permanent tidal correction: No

7 - Tectonic plate model: ITRF-92 plus adjustments

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

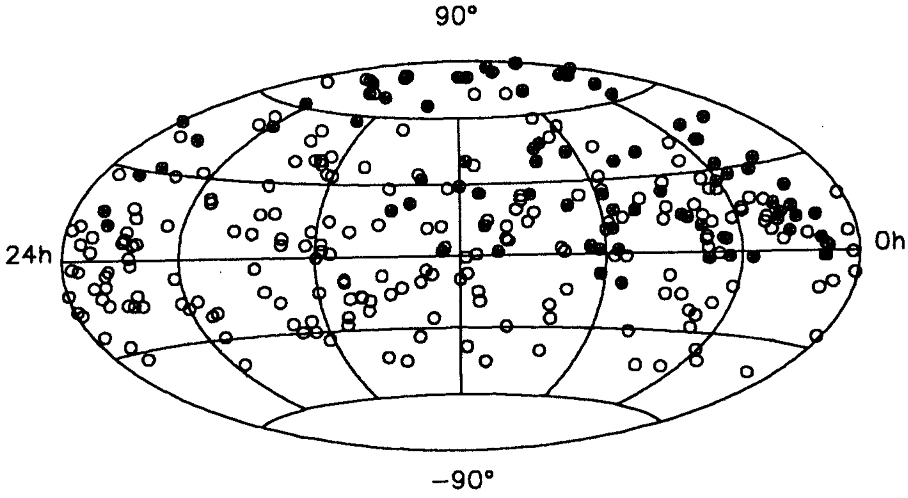
9 - Geogravitational constant: 3.9860 0448 10^{14} $m^3 s^{-2}$

10 - Reference epoch: 1 Jan 1988

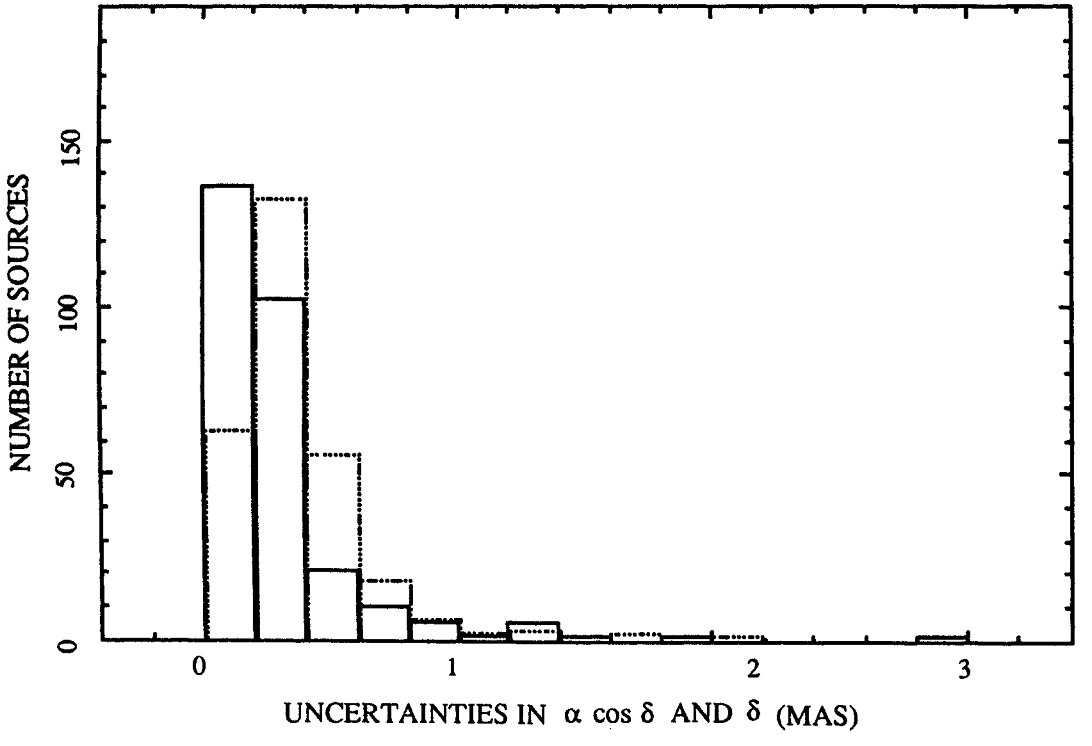
11 - Adjusted parameters: X0, Y0, Z0, $\dot{X}, \dot{Y}, \dot{Z}$

12 - 13 - Definition of the origin and orientation:
Six constraints were applied (with 5 mm uncertainty) to the nine coordinates (at epoch 1988.0) of DSS 15, DSS 45, and DSS 65, such that if a seven parameter transformation (3 translations, 3 rotations, 1 scale) between the JPL 1994-1 and ITRF-92 systems were 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. See text for details.

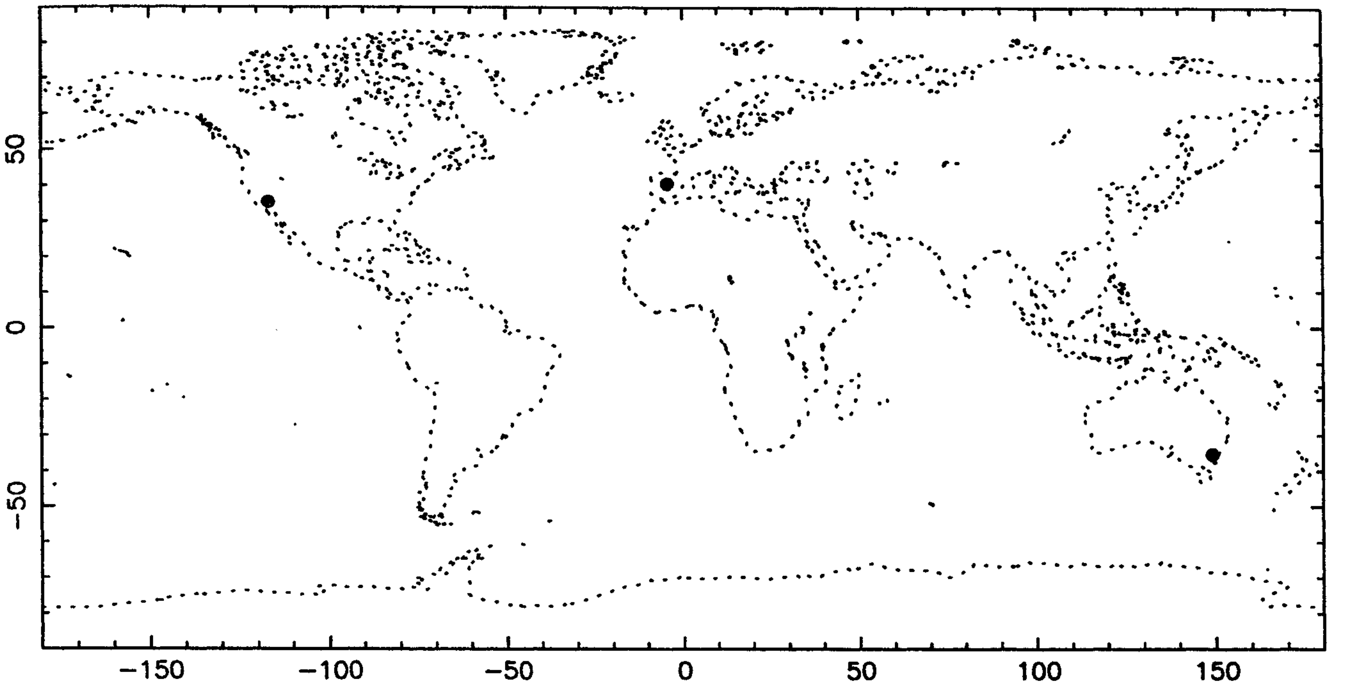
14 - Constraint for time evolution:
Six constraints were applied (with 1.0 mm/yr uncertainty) to the nine site-velocity parameters of the DSN network so as to yield no-net-translation-rate and no-net-rotation-rate with respect to the net motion of the three sites Madrid, Goldstone, and Canberra as specified by the ITRF-92 velocity field. See text for details.



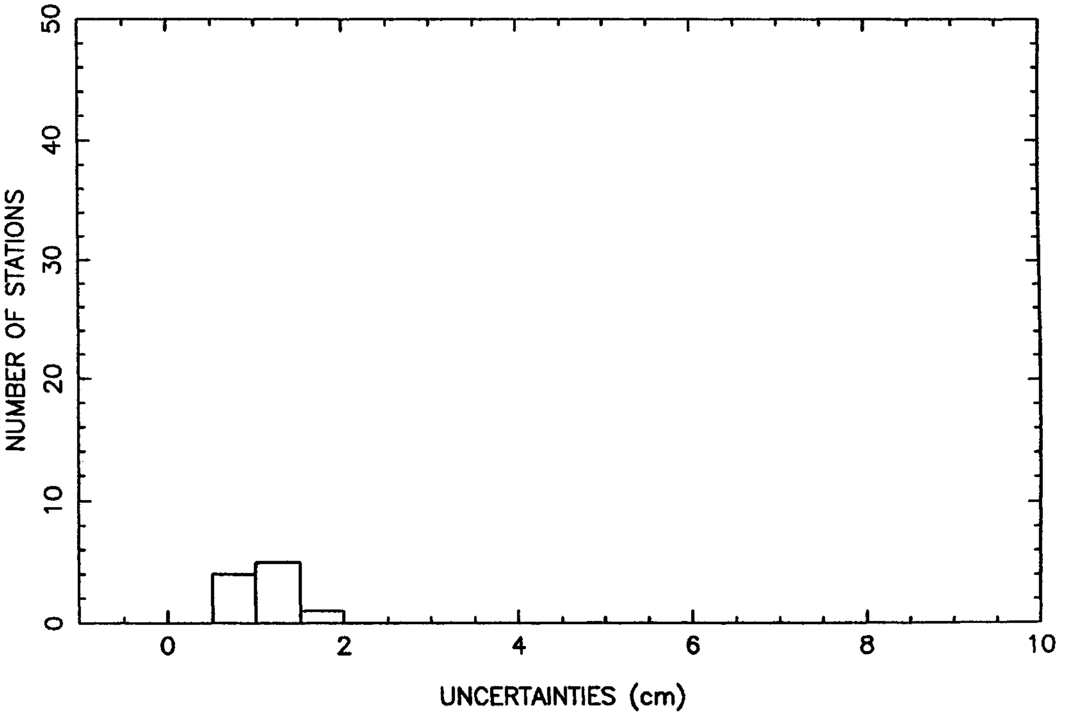
Distribution over the sky of the 285 extragalactic radio sources of the celestial frame RSC(JPL) 94 R 01. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(JPL) 94 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) 94 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) 94 R 01.

EOP(JPL) 94 R 01 From Oct 1978 to May 1994

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

YEAR	φ		UTO	
	Nb	Sigma	Nb	Sigma
1978	3	0.43	3	1.15
1979	6	1.82	6	1.88
1980	21	4.04	21	5.78
1981	17	2.69	17	5.62
1982	43	3.57	43	4.44
1983	74	3.23	74	4.75
1984	71	3.43	71	5.35
1985	19	2.19	19	3.93
1986	71	2.55	71	3.38
1987	77	2.07	77	3.35
1988	93	1.54	93	2.22
1989	93	0.62	93	1.71
1990	108	0.90	108	1.81
1991	111	0.44	111	1.02
1992	114	0.40	114	0.69
1993	101	0.62	101	0.95
1994	38	0.95	38	0.90

ANALYSIS OF VLBI OBSERVATIONS, 1984-1993

NAOMZ 94 R 01, 02

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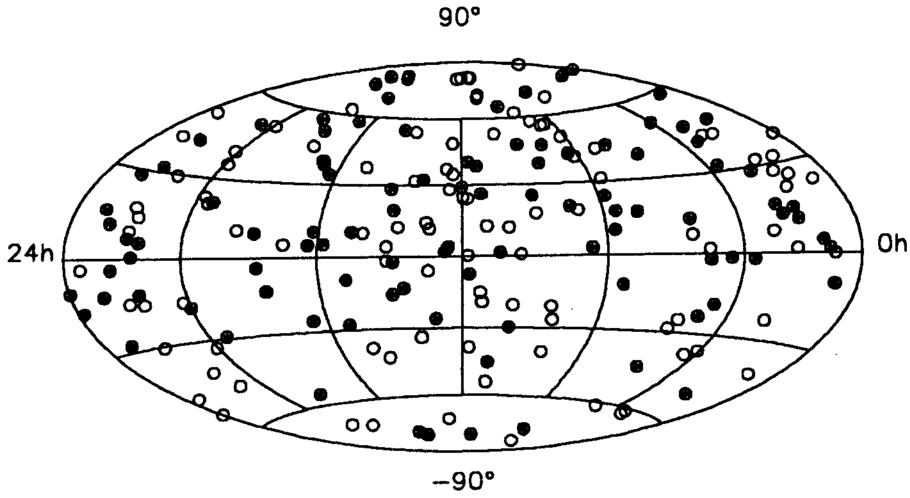
Mizusawa Astrogeodynamics Observatory, National Astronomical Observatory, Japan

The report contains the results of the analysis of the VLBI observations from 1984-1993 conducted under IRIS and CDP. The analysed material contains most of the IRIS-A and -P and part of the IRIS-S and CDP observations.

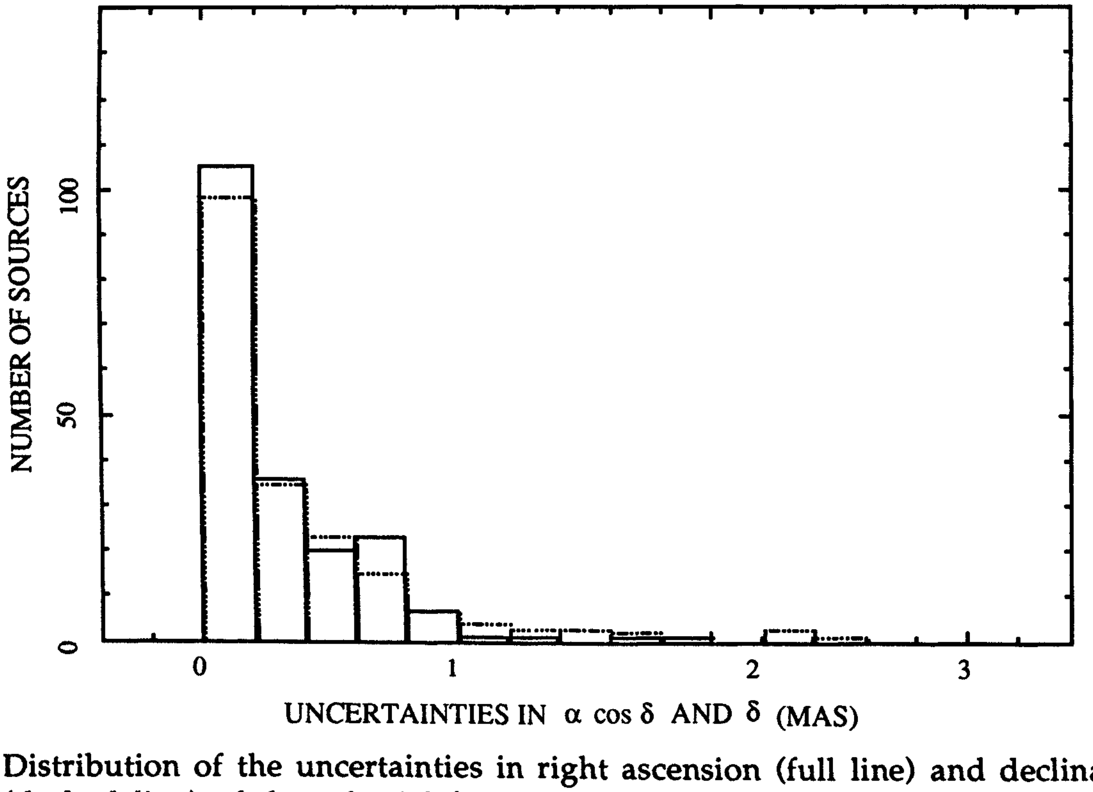
The basic system of the astronomical and geophysical constants are the IERS standards. However, there are some points differing from them. The vertical displacements of the station due to the atmospheric loading are corrected by adopting the method by Manabe (1991). Another difference is in the ocean loading effect on station positions. The displacements are computed with GOTIC by Sato and Hanada (1984) on the basis of Schwiderski's tidal map with the modification to conserve the mass of the oceans. Niell's (1993) NHMF2 is used as the mapping function of the atmospheric delay. The programs used in the analysis are the Mizusawa version of CALC, MSLV3 and GLK. MSLV3 and GLK correspond to SOLVE and GLOBL of Mark III.

Summary of the solutions NAOMZ 94 R 01 and R 02

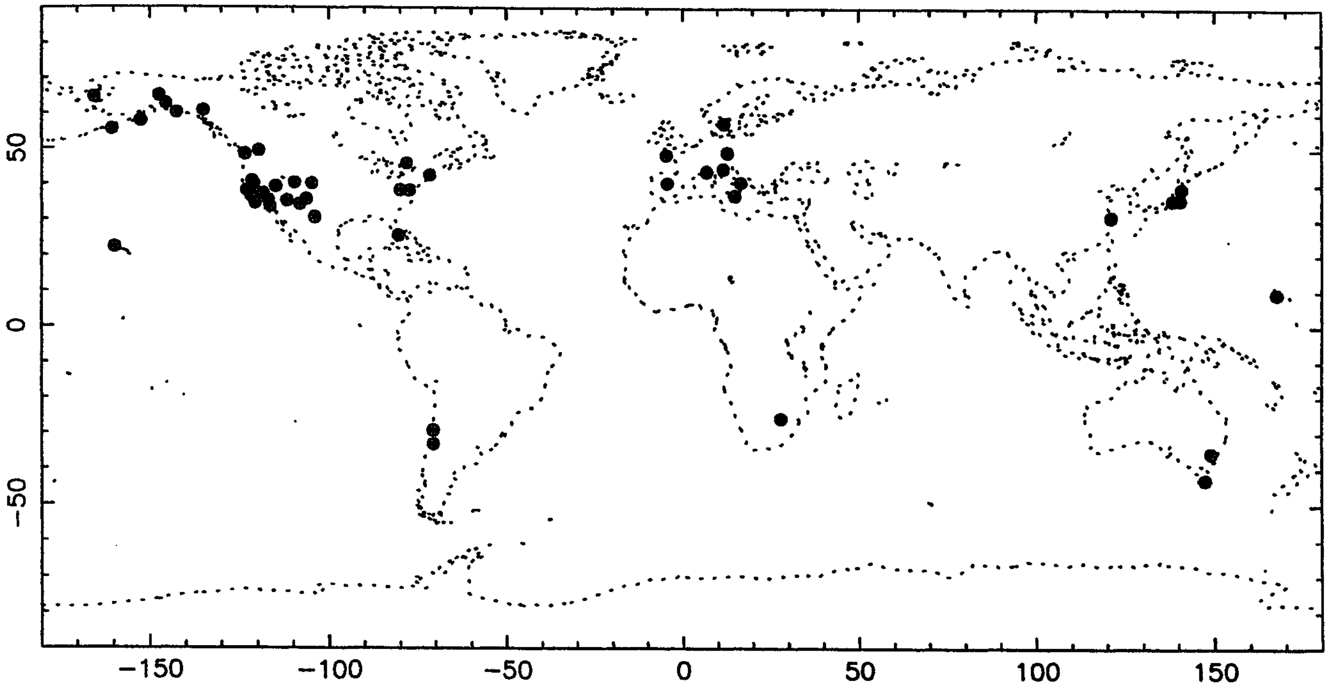
1 - Technique:	VLBI
2 - Analysis Center:	Mizusawa Astrogeodynamics Observatory, National Astronomical Observatory, Japan
3 - Solution identifier:	SG000084
4 - Software used:	CALC3, MSLV3 and GLK developed at Mizusawa
5 - Relativity Scale:	
6 - Permanent tidal correction on station:	yes
7 - Tectonic plate model:	NUVEL-NNR
8 - Velocity of light:	
9 - Gravitational constant:	
10 - Reference epoch:	1988.0
11 - Adjusted parameters:	EOP, station coordinates and velocities, radio source positions
12 - Definition of Origin:	Westford's coordinates(m) (1492206.755, -4458130.499, 4296015.503)
13 - Definition of Orientation:	Mean orientation of GILCREEK, ONSALA60, NRAO85 3, WETTZELL, RICHMOND, WESTFORD, KAUAI and mean of KASHIMA and KASHIM34 are adjusted to that of ITRF92.
14 - Constraint for time evolution:	linear in time



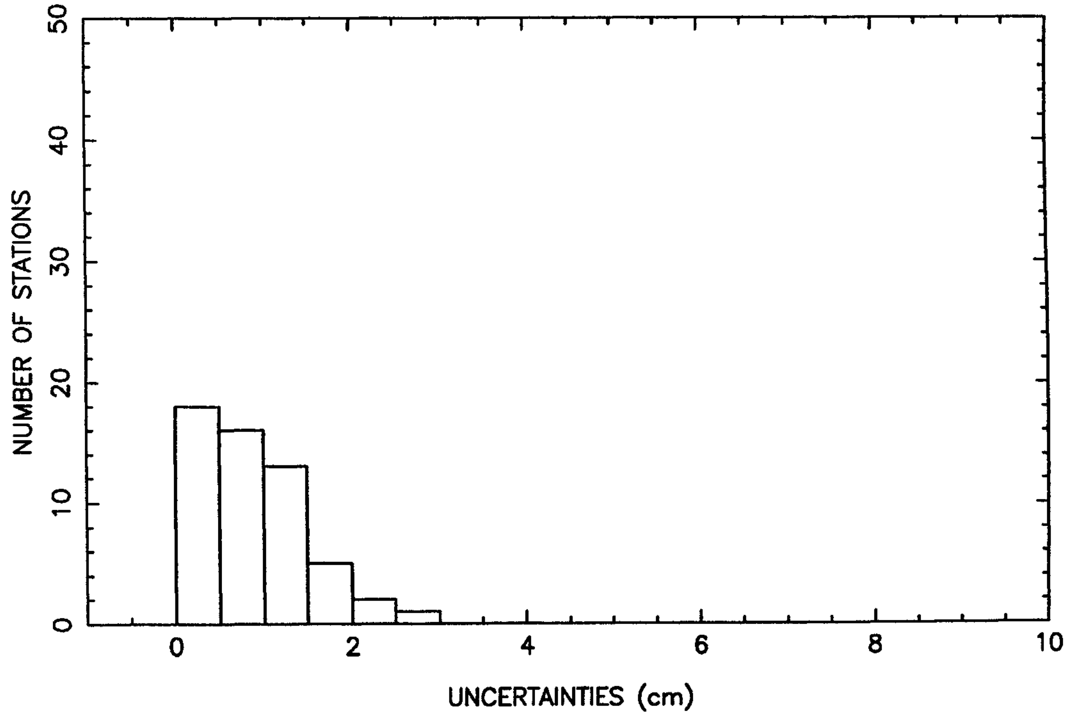
Distribution over the sky of the 206 extragalactic radio sources of the celestial frame RSC(NAOMZ) 94 R 01. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(NAOMZ) 94 R 01. 10 radio sources with uncertainties larger than 0.003" are not shown.



Distribution of the 49 sites of the terrestrial frame SSC(NAOMZ) 94 R 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 55 stations of the terrestrial frame SSC(NAOMZ) 94 R 01.

EOP(NAOMZ)94 R 02 — From Jan 1984 to Feb 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
1984	76	0.63	76	0.56	76	0.30	76	0.72	76	0.26
1985	77	0.60	77	0.54	77	0.28	77	0.65	77	0.24
1986	92	0.62	92	0.54	92	0.29	92	0.68	92	0.26
1987	101	0.61	102	0.56	102	0.30	102	0.71	102	0.26
1988	106	0.55	106	0.50	106	0.28	106	0.61	106	0.25
1989	165	0.50	165	0.48	165	0.25	165	0.61	165	0.24
1990	174	0.33	173	0.38	174	0.18	174	0.44	174	0.19
1991	143	0.24	143	0.26	143	0.12	143	0.36	143	0.14
1992	148	0.27	148	0.27	148	0.11	148	0.41	148	0.17
1993	72	0.20	72	0.17	72	0.07	72	0.32	2	0.13
1994	5	0.12	5	0.11	5	0.05	5	0.21	5	0.09

NOAA EARTH ORIENTATION AND REFERENCE FRAME RESULTS DERIVED FROM VLBI OBSERVATIONS: 1994 ANALYSIS PROCEDURES

NOAA 94 R 01, 02

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1. Introduction

Estimated values for terrestrial site coordinates and velocities, radio source coordinates, and a time series of Earth orientation parameter (EOP) values have been determined from a composite set of Mark III Very Long Baseline Interferometry (VLBI) data. The data sets included were collected under the sponsorship of several national and international agencies and programs with a wide variety of objectives. A total of 1,009,298 bandwidth-synthesis group delay observables amassed during 1609 one-day observing sessions between 1980 September and 1994 March were combined in a single least-squares adjustment to obtain an EOP time series (EOP(NOAA) 94 R 01), coordinates for 176 radio sources (RSC(NOAA) 94 R 01), and geocentric coordinates and velocities for 106 VLBI reference points (SSC(NOAA) 94 R 01).Unlike past years, our EOP time series is not partitioned into two distinct files so as to emphasize the unitary nature of the VLBI analysis.

In addition, a separate series of quasi-daily UT1 values for the period 1984 April - June and 1985 April to 1994 March has been produced; EOP(NOAA) 94 R 02 contains results from 2224 sessions. These UT1 values were determined from a special series of 'Intensive' observing sessions using only a single east-west baseline for about one hour each day [Robertson *et al.*, 1985], sufficient to determine only UT1. Usually, the WESTFORD-WETTZELL baseline was used for Intensive observations, although a small number of sessions have used either NRAO85-3 or MATERA. The EOP(NOAA) 94 R 02 Intensive UT1 time series is produced separately but is otherwise fully consistent with the UT1 values in the EOP(NOAA) 94 R 01 series from the 24-hour observing sessions.

The most significant changes since our submission last year [Carter *et al.*, 1993] are summarized below. Detailed discussions of these items are presented in the following sections.

• The total number of VLBI observations analyzed has increased almost 45%, including data from 51 more sites and 69 new radio sources. Apart from including new observational data collected during 1993, the significant additional data source was the assimilation of 234 sessions involving 37 mobile VLBI sites throughout N. America. In addition, first data from the following new facilities were included: six of the 25-m VLBA antennas; the 14.2-m antenna at Fortaleza (Brazil); the 20-m Kokee antenna on Kauai (Hawaii, USA); the 9-m antenna at the O'Higgins Base (Antarctica); and the 10-m dish at Mizusawa (Japan).

• The modelling of the elevation angle dependence of the tropospheric path delay has been changed from the CfA-2.2 model [Davis *et al.*, 1985] for the "dry" delay plus the Chao [1972] model for the "wet" delay to the new NMF "dry" and "wet" models [Niell, 1993 and in preparation]. The main consequence of this change is a reduction in the scale of the NOAA terrestrial reference frame by nearly 3 parts per billion (ppb).

• The no-net-rotation (NNR) version of the NUVEL-1A global plate motion model [DeMets *et al.*, 1994] has been used instead of the previous NNR-NUVEL-1 model. The new model yields rates that are scaled by the factor 0.9562 compared with NUVEL-1 due to recent recalibration of the geomagnetic time scale. This change affects the net rotational and translational velocity constraints applied to the VLBI system and the projected geocentric coordinates for those sites with insufficient measurement histories to permit direct velocity determinations. The number of sites used to specify the net velocity constraints has been increased from 9 to 10.

• Seven pairs or triplets of adjacent sites have been constrained to have the same velocity estimates. Instances of nearby sites with independently robust velocity determinations have not been linked in this way.

• New fixed EOP values for the reference epoch 1991 August 12 19:49:50 (see below) have been computed based on the series EOP(IERS) 90 C 04 with appropriate consistency corrections applied for the latest realization of the ITRF and ICRF. The changes in our EOP reference values are -0.1058 mas, +0.2729 mas, +0.075 ms, - 0.4155mas, and +0.3053 mas for x, y, UT1, ψ, and ε, respectively. The combined effect of all changes in our new analysis procedures produces total shifts in our current EOP series of -0.2068 mas, +0.2741 mas, +0.076 ms, -0.3826 mas, and +0.2644 mas, respectively.

• The constraint defining the geocentric coordinate origin of the NOAA terrestrial reference frame has been updated to use ITRF-92 coordinates rather than ITRF-91 values; see Dillinger *et al.* [1993] for a description of the constraint algorithm. The set of constraining sites has been increased from 16 to 20. Compared to the previous realization, the origin of ITRF-92 is shifted by -1.1, -1.4, and 0.6 cm in X, Y, and Z, respectively, and the scale is smaller by 1.4 ppb [Boucher *et al.*, 1993].

• The constraint defining the right ascension (RA) origin of the NOAA celestial reference frame has been updated to use ICRF-92 coordinates rather than

ICRF-91 values. In addition, the constraint algorithm [Dillinger *et al.*, 1993] has been modified so that in forming the sum of adjusted RA values each contributor is weighted by the cosine of its declination in order to de-emphasize sources near the celestial poles. The set of constraining radio sources has been changed to include all common sources designated as "primary" in the ICRF-92 catalog thereby increasing the number of constraining sources from 36 last year to 71.

2. Summary of Analysis Procedures

The VLBI observations were analyzed at NOAA in general conformance with the latest IERS Standards [McCarthy, 1992]. Below, the specific approaches used in the NOAA solution to implement these standards are described with emphasis on areas of departure and on changes from our previous submission:

• The right ascension (RA) origin of the NOAA celestial reference frame at epoch J2000.0 is specified by constraining the sum of the adjusted RA values for 71 radio sources, each weighted by the cosine of its declination, to be equal to the corresponding value obtained from the IERS Celestial Reference Frame ICRF-92. The constraint algorithm differs from that used last year and described by Dillinger *et al.* [1993] by the inclusion of the cosine(declination) weighting. The set of 71 constraining sources include all those designated as `primary' in the ICRF-92 catalog which are common to the two frames. Previously, 36 sources, preferentially but not necessarily primary, were used for the RA constraint.

• The geocentric origin of the NOAA terrestrial reference frame is specified for the epoch 1988.0 by requiring that the vector sum of the adjusted station coordinates be equal to the corresponding sum for the IERS Terrestrial Reference Frame ITRF-92 for the set of 20 VLBI sites listed below:

Westford,	MA, USA *
Richmond,	FL, USA *
Algonquin Park,	Ont., Canada *
Gilmore Creek, Fairbanks,	AK, USA *
NRAO85-3, Green Bank,	WV, USA *
Platteville,	CO, USA *
Mojave,	CA, USA
Owens Valley,	CA, USA
Vandenberg,	CA, USA
Onsala,	Sweden *
Effelsberg,	Germany *
Wettzell,	Germany *
Kashima,	Japan
Shanghai,	China
DSS-65, Madrid,	Spain
Kauai,	HI, USA *
Kwajalein Atoll,	Marshall Islands
Hobart, Tasmania,	Australia
DSS-45, Tidbinbilla,	Australia
Hartebeesthoek,	South Africa

The Pie Town (NM, USA) VLBA station was dropped from the list of constraint sites used last year while EFLSBERG, MOJAVE12, OVRO_130, VNDNBERG, and KASHIMA were added. We note that the origin of ITRF-92 is shifted by -1.1, -1.4, and 0.6 cm in X, Y, and Z relative to ITRF-91, which was used for our origin constraint last year, and the scale of ITRF-92 is smaller by 1.4 ppb [Boucher *et al.*, 1993].

Because the three-dimensional linear velocity of each VLBI site is estimated in the data analysis while the secular motions of the VLBI frame itself are indeterminant, it is necessary to impose additional constraints to define the translational and rotational motions of the entire terrestrial frame. This is done by requiring the vector sum of the translational velocities estimated for a set of 10 VLBI sites be equal to the corresponding vector sum obtained assuming station velocities as predicted by the NNR-NUVEL-1A global plate motion model [DeMets *et al.*, 1990; Argus and Gordon, 1991; DeMets *et al.*, 1994]. The angular velocity of the frame is constrained by requiring the vector sum of the rotational velocities formed from the cross products of each site velocity with its Earth radius vector be equal to the corresponding vector sum obtained from the NNR-NUVEL-1A model for the same set of 10 sites. See Dillinger *et al.* [1993] for details of the constraint equations. The 10 sites used for the velocity constraints are indicated in the list above with asterisks; with the addition of EFLSBERG, the list is otherwise the same as last year. This particular subset was chosen to obtain as large a geographical extent as possible while retaining the closest possible match to rigid plate model motions and avoiding peculiar local site motions or regions of large-scale tectonic deformation. NNR-NUVEL-1A is the no-net-rotation version of the NUVEL-1A plate motion model, a recalibration of the previous NUVEL-1 model to account for revisions to the geomagnetic time scale; all angular velocities are 4.38% smaller in NUVEL-1A [DeMets *et al.*, 1994].

The velocity values used to project station coordinate values to arbitrary epochs for those sites with brief data spans, usually less than about two years, are adopted from the NNR-NUVEL-1A model. (However, velocity parameters are adjusted in the data analysis for all sites, including those with brief data spans.) There are 34 sites in SSC(NOAA) 94 R 01 with coordinate projection done using model velocities. They are denoted by having velocity formal errors equal to zero. In several cases, more than one reference point has been measured at a given site but only one point has an adequate history to permit a robust velocity determination. These include sites with collocated mobile occupations adjacent to permanent fixed VLBI antenna locations, shifts in VLBI operations from one permanent antenna to another nearby, and discontinuities due to episodic earthquake motions. We have distinguished post-earthquake sites by modifying their VLBI station names to change the last two characters to `pq'. In all such instances, the VLBI reference points are assumed to have identical long-term velocities and constraints to this effect have been applied in the analysis. For sites affected by earthquake motions, this assumption is consistent with the analysis of Argus and Lyzenga [1994]. Sites whose velocity parameters have been linked in this manner are:

MOJAVE12	- MOJ_7288	- MOJAVEpq
OVRO_130	- OVR_7853	
KAUAI	- KOKEE	
GORF7102	- GGAO7108	
FORT_ORD	- FORTORDS	- FORTORpq
YAKATAGA	- YAKATApq	
YELLOWKN	- YLOW7296	

Other cases of adjacent VLBI sites having independently robust histories for velocity determinations, such as WESTFORD and HAYSTACK, have not been specially constrained.

• In the transformation between the celestial and terrestrial systems, the conventional formulation has been used except that the true obliquity of date is used in the equation of the equinox rather than the mean obliquity of date. Geodesic nutation is not taken into account. While the estimated nutation offset values reported here are with respect to the IAU 1980 model, the time variation of the nutation offsets between tabular points in the EOP a priori file used in our data analysis is assumed to follow the ZMOA-1990-2 model of Herring [1991]. The procedure used for the interpolation of a priori nutation offset values is analogous to the procedure described below for tidal variations in the Earth's rotation. The orientation of the systems is specified by fixing the values for the EOP and nutation offsets to agree with those interpolated from the EOP(IERS) 90 C 04 series for the reference epoch 1991 August 12 19:49:50. This particular EOP reference epoch was chosen because two large, independent VLBI networks ran simultaneously that day: IRIS-A701 used Mojave (Goldstone, CA, USA), Richmond (FL, USA), Westford (MA, USA), and Wettzell (Germany) while Polar-N2 used Gilcreek (Fairbanks, AK, USA), DSS-13 (Goldstone, CA, USA), Haystack (Westford, MA, USA), Kashima (Japan), and Onsala (Sweden) and together the two sessions produced 2062 usable observations. The EOP values for the reference epoch were computed in a two-step process somewhat changed from last year: first, linear interpolation was performed between tabulated values in the series EOP(IERS) 90 C 04 for 1991 August 12 and 13 (after correcting for the offsets and drift rates reported by the IERS to give consistency with the ITRF-92 and ICRF-92 frames [IERS, 1993]); then, contributions due to diurnal and semi-diurnal variations of polar motion x, y, and UT1 were added based on the model of Herring [1993]. The values so determined for the reference epoch (MJD 48480.8262731479) are given in Table 1. Also shown in Table 1 are the EOP reference values used in our analysis last year and the change for each component. These are compared with the changes in the IERS system itself due to different realizations of the terrestrial and celestial reference frames in 1991 and 1992; see the rightmost column.

Table 1. Fixed EOP values for reference epoch 1991 August 12 19:49:50

EOP	value this year		value last year	change	IERS change
x =	136.4637	[IERS]			
	-.0616	[d/sd]			
=	136.4021 mas		136.5079 mas	-0.1058 mas	-0.3252 mas
y =	554.4026	[IERS]			
	-.4195	[d/sd]			
=	553.9831 mas		553.7102 mas	+0.2729 mas	+0.2000 mas
UT1 =	171.218	[IERS]			
-UTC	+.021	[d/sd]			
=	171.239 ms		171.164 ms	+0.075 ms	+0.0534 ms
psi =	-17.1806 mas		-16.7651 mas	-0.4155 mas	-0.4000 mas
eps =	-4.4022 mas		-4.7075 mas	+0.3053 mas	+0.3000 mas

Note: [IERS] refers to values interpolated linearly from EOP(IERS) 90 C 04 after correcting for annual offsets and drift rates needed to achieve consistency with the ITRF-92 and ICRF-92 frames; [d/sd] refers to the diurnal and semi-diurnal corrections from the model of Herring [1993].

- Solid Earth tide displacements are accounted for using the recommended correction to the K1 term without any correction to remove the zero-frequency "permanent tide" displacement. Values for the Love number h2 and Shida number l2 are 0.60967 and 0.0850, respectively, rather than the IERS Standards (1992) values of 0.6090 and 0.0852. Rotational deformation due to polar motion, "pole tide", is also included.

- Radial and tangential displacements due to ocean loading are included but atmospheric loading effects are not. No adjustments were made to account for internal deformations of the VLBI antenna structures. 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 acquisition systems.

- Tidal variations in the Earth's rotation are taken into account in forming a priori values for the EOPs in the VLBI data analysis. Since an offset adjustment to each EOP is made for each 24-hour observing session, the results are most sensitive to those tidal variations with periods shorter than about one day. The procedure used to form a priori EOP values at each VLBI observation epoch is unchanged from last year and consists of the following steps: 1) tabulated EOP values are taken from a previous NOAA solution for the set of all IRIS-A, NAVNET, and NEOS-A observing sessions; 2) known tidal contributions based on models described below are removed; 3) a cubic spline interpolation is performed on the tidally corrected EOP values from the five nearest tabular epochs; 4) model tidal contributions are restored. The models used for the tidal contributions are: 1) UT1S tidal terms, including periods between 5.64 days and 18.6 years with corrections due to oceanic tides (see IERS Standards, McCarthy, 1992); 2) diurnal and semi-diurnal variations of x,y, and UT1 derived by Herring [1993] based on analysis of 8.5 years of VLBI data. To minimize the effects of unmodelled

Earth orientation variations, the VLBI adjustments of EOP values are made at the weighted mid-point epoch of each observing session.

• Tropospheric refraction in the local zenith direction caused by the "dry" (hydrostatic) and "wet" (water vapor) components of the neutral atmosphere has been modelled a priori according to Saastamoinen [1972] using surface meteorological data (pressure, temperature, humidity) taken at each VLBI station during each observing session. The zenith delays are mapped to line-of-sight elevations with the NMF dry and wet models [Niell, 1993 and in preparation]. Residual atmospheric delay, presumably due to the wet troposphere, is treated by adjusted parameters (see below) using the NMF wet elevation mapping function. The new NMF mapping functions perform comparably to the MTT mapping functions of Herring [1992]. However, the bias in the hydrostatic mapping is significantly smaller [Niell, private communication] which should minimize potential scale errors in the terrestrial and celestial reference systems. In addition, because the NMF functions do not rely on surface met data, those VLBI sessions which lack met data can be combined with other sessions with less risk of biases due to inhomogeneties. This year's change in tropospheric mapping functions, by itself, causes a reduction in the NOAA terrestrial reference frame of about 2.7 ppb. The dispersive portion of the atmospheric refraction due to the ionosphere is eliminated by the use of simultaneous dual-frequency (X- and S-band) observations.

• Shapiro's formulation for the general relativistic effects of signal propagation is used (see the previous edition of the IERS Standards, McCarthy, 1989) rather than the newer model recommended in the 1992 edition. We expect Shapiro's algorithm to agree within a few picoseconds (about 1 mm or better) with the newer algorithm.

The full set of group delay observations was processed at the NOAA VLBI Analysis Center in Silver Spring (MD, USA) using the CALC-7.6 program (see the appendix in Caprette *et al.*, 1990) to compute the theoretical delays and their partial derivatives, and using the SOLVE-3 program [Dillinger and Robertson, 1986] for the least-squares parameter adjustment. A single least-squares solution was performed using sparse-matrix handling techniques [Dillinger and Robertson, 1986] and constraint algorithms [Fallon and Dillinger, 1992; Dillinger *et al.*, 1993]. Delay rate observations are not included, nor any observations with an elevation angle lower than 5 degrees. The solution was done with a forward pass to reduce and combine all the data to determine values for the "global" parameters (those values are affected by all observing sessions) followed by a separate step to determine the "arc" parameters (those affected only by data from an individual observing session). The geocentric coordinates and three-dimensional linear velocities of the stations and the J2000.0 celestial coordinates of the radio sources are determined globally. The only constraints applied in the estimation of the global parameters are those described above to remove inherent singularities associated with the right ascension origin of the celestial frame, the geocentric coordinate origin of the terrestrial frame, and the translational and rotational velocities of the terrestrial frame. The site coordinate parameters are adjusted at the weighted mean observation epoch for each site, rather than at an arbitrary epoch, in order to remove singularities that can arise when simultaneously adjusting coordinates and velocities for those sites with brief data spans. Site coordinate values are produced for arbitrary common epochs by projection of the mean-epoch coordinates using the estimated velocity values. Epoch projection of station coordinates for those with brief data spans is done with NNR-NUVEL-1A velocities rather than with the estimated velocity values. The site coordinates refer to the intersection of the pointing axes of the fixed antennas (designated by a four-digit number and cataloged by the NASA Space Geodesy Program) or to reference ground monuments in the case of sites occupied by mobile VLBI systems.

Arc parameters are used to model both nuisance effects (clock and atmospheric delays) and the important EOP variations (x and y pole position, UT1, offsets in nutation obliquity and longitude). Time variations in the station clock differences are treated by estimating coefficients of polynomials, usually one or two second-order polynomial segments per day per station. Residual ("wet") atmospheric delays are treated by estimating the values of a piece-wise linear, continuous function at break-points set every hour for each station of each observing session. A weak constraint is applied to the variation of the atmosphere parameters between break-points; see Dillinger *et al.* [1993]. One offset parameter is adjusted for each Earth orientation component per observing session. The EOP adjustments are computed at the weighted mean observation epoch of each observing session to minimize unmodelled effects in the a priori EOP variations. Some observing sessions are geometrically limited to such an extent that the estimation of all EOP components is singular or nearly so. These sessions include single-baseline data sets (Hartebeesthoek-Hobart) and relatively small networks, usually involving a mobile VLBI system in a regional observing program. For these cases (totalling 183 sessions of which 143 are from the newly added N. America mobile VLBI campaigns), weak a priori constraints are applied (see Dillinger *et al.*, 1993). The constraints use EOP values interpolated from the tabulated a priori EOP series with weights equal to 50 times the a priori weight based on linear interpolation of the formal uncertainties of the tabulated EOP values. The effect of this constraint is that the formal uncertainties of estimated EOP values are never larger than about 3 mas since about 1985 when regular, high-quality VLBI determinations of EOP values became routine.

The full solution included 1,009,298 group delay observations and 166,225 constraint equations to adjust a total of 221,488 parameters.

The standard errors quoted here are strictly the formal values obtained from the parameter adjustments by the propagation of the formal observational noise together with an added contribution calculated for each baseline of each observing session to give a normalized postfit residual of unity. These standard errors should be understood as lower limits on the actual uncertainty of the determinations, the limit that would be attained in the absence of unmodelled systematic errors. Comparison of VLBI station coordinates with independent determinations using satellite laser ranging (SLR) indicates that the formal standard errors are probably optimistic by a factor of about two [Ray *et al.*, 1991].

The Intensive UT1 observations use a single east-west baseline, generally from Wettzell (Germany) to Westford (MA, USA). Through late 1991, eight observations were made of four different sources within each one-hour observing session conducted six days per week. Since that time, the observing mode has been upgraded to permit twice as many observations in each one-hour session. For brief periods, the Matera (Italy) station has substituted for Wettzell and the NRAO85-3 antenna (at Green Bank, WV, USA) for Westford. Beginning 1994 February 24, Intensives operations were moved from Westford to NRAO85-3 permanently. The observations are analyzed in a solution using the terrestrial and celestial reference frames and EOP values established by the 24-hour sessions described above. Only a UT1 offset, a clock offset, and a clock rate parameter are adjusted for each Intensive session.

3. Discussion of Results

3.1 Celestial Reference Frame:

The current NOAA celestial reference frame consists of 176 radio sources, an increase of 69 sources over last year. Of these sources, 71 are designated "primary" in the IERS Celestial Reference Frame ICRF-92. The right ascension origin of the NOAA frame is defined by a constraint to match ICRF-92 for the subset of 71 primary sources (see discussion above). By distributing the origin constraint over as many different sources as possible, it is expected that systematic errors associated with individual objects, such as time-varying brightness structures and variations in the history of VLBI observing, will be significantly reduced affording enhanced long-term stability of the system. It is expected that any non-rotational deformations in our frame [IERS, 1993], to the extent that they may be caused by biases in the modelling of tropospheric refraction, will be reduced in this year's submission due to the implementation of the NMF mapping function (see previous discussion).

The mean (or weighted mean) and root-mean-squared (rms or weighted rms) differences between our RSC(NOAA) 94 R 01 celestial frame and the ICRF-92 are shown in Table 2 for the set of 71 primary sources in common, for all sources in common, and for all sources in common except three. For the latter two sets, the reported formal uncertainties for both catalogs have been used to compute weighted mean and weighted rms (about the mean) values. In all cases the mean differences are quite small. The scatters are also small and consistent with the quoted formal uncertainties except for the RA scatter of the full source set. This discrepancy is caused by a very poor RA value for 0733-174, which was recently corrected by nearly 800 mas [Eubanks, private communication]. Excluding this source, 0316+413 (3C84), and 1947+079 from the statistics gives scatter results roughly consistent with the reported formal uncertainties; reduced chi-squared values are 1.15 and 1.37 for the RA and declination differences, respectively.

There are 11 sources being submitted in RSC(NOAA)94R01 which are not contained in the ICRF-92 catalog: 0010+405, 0108+388, 1053+704, 1128-047, 1307+121, 1409+218, 1417+273, 1420+326, 1424+240, 1432+200, and 1433+304. Data for all these are sparse, in one case relying on only four observations.

Table 2. Differences between RSC(NOAA) 94 R 01 and ICRF-92

	RA (mas)	RA * cos(dec) (mas)	dec (mas)
71 "primary" sources in common:			
mean	-0.018	= 0.000	-0.007
rms	0.351	0.241	0.299
all 165 sources in common:			
weighted mean	-0.011	-0.018	-0.016
weighted rms	2.538	2.038	0.341
162 sources in common: *			
weighted mean	-0.023	-0.026	-0.010
weighted rms	0.205	0.163	0.229

* Excluding 0316+413 (3C84), 0733-174, and 1947+079; see text. The mean difference in RA*cos(dec) is constrained to be zero for the 71 primary sources.

3.2 Terrestrial Reference Frame:

The motivation and procedure for defining the coordinate origin of the NOAA terrestrial reference frame were discussed in last year's report by Carter *et al.* [1993]. The NOAA site positions are adjusted so that the origin matches the IERS Terrestrial Reference Frame, ITRF-92, for a subset of 20 out of the full set of 106 VLBI sites. Connection of each VLBI station's position to the origin constraint is improved by distributing the constraint over as large a network as possible. Unlike the celestial RA constraint, however, the realization of the terrestrial origin constraint is severely limited by the available geographic distribution of VLBI sites. A roughly uniform, global distribution of constraint sites would be preferred but the actual distribution, especially for sites with lengthy observing histories, is highly restricted. With these considerations in mind we have added five sites to the origin constraint this year: EFLSBERG, MOJAVE12, OVRO_130, VNDNBERG, and KASHIMA. Even though EFLSBERG is included in only six observing sessions, its history spans more than 13 years which yields very precise position and velocity determinations. The other new origin constraint sites lie in deformation zones near plate boundaries and were excluded for this reason last year. However, because ITRF-92 combines position determinations wherein non-plate motions are accounted for, this restriction does not appear necessary. Meanwhile, the PIETOWN VLBA site has been dropped from our origin constraint because its anomalous measured motion last year (-22.4 mm per year in the local vertical direction) cast doubt on the reliability of coordinate projection to epoch 1988.0.

Table 3 presents the coordinate transformation parameter values relating the NOAA terrestrial reference frame to ITRF-92 for the 20 sites used in the origin constraint. The largest value is the rotation about the X-axis which corresponds to a shift of about 17.7 mm at the Earth's surface. The largest contribution to the rms residual comes from Hobart with differences of -29.1, 13.9, and -2.6 mm in X, Y, and Z, respectively. The next largest residuals are due to DSS65 (Madrid) and DSS45 (Tidbinbilla) at less than half that level. It appears likely that the Hobart discrepancy is caused by a significant change in its measured velocity since last year (see below) coupled with a relatively large time offset of 4.1 years between the 1988.0 coordinate reference epoch and the mean epoch of Hobart data.

Table 3. Coordinate transformation from ITRF-92 to SSC(NOAA)94R01 *

Transformation parameter	value	error
Rot. about X	0.573 mas	0.069 mas
Rot. about Y	0.054 mas	0.068 mas
Rot. about Z	0.078 mas	0.064 mas
X translation	-1.0 mm	1.7 mm
Y translation	8.3 mm	1.8 mm
Z translation	2.1 mm	1.7 mm
scale difference	0.3 ppb	0.3 ppb
3-D rms residual	10.6 mm	

* For the 20 VLBI sites defining the origin of the coordinate system, equally weighted.

The overall translational and rotational velocities of the NOAA terrestrial reference frame are specified through a set of constraints similar to the specification of the coordinate origin except that only 10 VLBI sites are used in the velocity constraints and the defining motions are adopted from the NNR-NUVEL-1A global plate motion model. There are two important distinctions in the application of these constraints compared with the celestial and terrestrial coordinate origin constraints: 1) The estimated site velocity values are unavoidably coupled to the secular drifts in the Earth orientation parameters (EOPs) which produces a small, but significant non-linear dependence on the a priori EOP series used in the data analysis. If the a priori EOP time series is not already consistent with the reference frames, iteration of the solution is required to produce a fully self-consistent, stable solution. 2) The external a priori information used in the frame velocity constraints -- the NNR-NUVEL-1A model for rigid plate motions [DeMets *et al.*, 1990; Argus and Gordon, 1991; DeMets *et al.*, 1994] -- is an idealized representation of relative terrestrial motions that is totally independent of VLBI results. On the other hand, the ICRF-92 and ITRF-92 coordinate values used in the origin constraints are combinations which include previous VLBI results. Thus, the match of the observational results to the constraint is unlikely to be as close for velocities.

These distinctions make the analysis results somewhat more sensitive to the selection of VLBI sites used for the velocity constraints than is true for the origin constraints. In general, one set of velocity constraint sites will produce a frame with significantly different translational and rotational rates compared with a different set of constraint sites. The resulting secular rates for the EOPs will also differ (typically, by 0.100-0.200 mas/yr). While the specification of these rates is arbitrary, some choices are preferred for practical reasons. For one, the NOAA frames are intended to match the IERS frames as closely as possible, partly to better maintain long-term stability. Also, since the coordinates for sites with brief VLBI occupations are projected in time using NNR-NUVEL-1A model velocities, we prefer to match the plate motions most closely over those portions of the Earth's surface where these sites are concentrated, primarily N. America and Europe. (However, for the same reason, coordinate values for sites projected to an epoch far from the observation epoch should be regarded with some caution, particularly since the projection is done assuming no uncertainty in the velocity values.) Empirically we have found that these objectives are reasonably well satisfied by our choice of 10 velocity constraint sites with six in N. America, three in Europe, and one in Hawaii. EFLSBERG was added to the set of nine velocity constraint sites used last year. The rms velocity residuals for the 10 constraint sites relative to NNR-NUVEL-1A motions are 1.7 mm/yr in the horizontal plane and 2.1 mm/yr in the vertical direction.

Table 4 shows the measured topocentric velocities for 40 VLBI sites having sufficiently long data spans, relative to the velocities predicted by the NNR-NUVEL-1A plate motion model. (For those sites with linked velocity estimates, only one site name is listed in Table 4.) There are, in addition, 23 mobile sites in western N. America whose motions are not shown in Table 4. Results for these sites, which lie mostly in tectonically deforming regions and which are generally not as well determined, especially in the vertical, have recently been reviewed by Gordon *et al.* [1993]. Also indicated in Table 4 are the sites used for the coordinate origin constraint and for the frame velocity constraints.

In the five cases in Table 4 of two or more independent sites located within a few kilometers of one another, indentation of the site names is used to denote the groupings. These results can be used as a gauge of the level of systematic velocity error that may be present. The most robust pair is HAYSTACK/WESTFORD, each of which has observed longer than a decade although WESTFORD has accumulated about 18 times as much data. Their velocities differ by -0.3, 0.3, and 0.9 mm/yr in N, E, U, respectively, only about one standard deviation or less in all three components. The Green Bank (NRAO_140 and NRAO85_3), Ft. Davis (HRAS_085 and FD-VLBA), Goldstone (MOJAVE12, GOLDVENU, and DSS15), and Kashima (KASHIMA and KASHIM34) groupings show poorer agreement with velocity differences up to 6 sigma in E at Green Bank and Ft. Davis and in U at Kashima. The 16.4 mm/yr downward motion of KASHIM34 seems possibly spurious.

Another measure of systematic error is the change in our velocity estimates this year compared to last year. Focussing on the vertical velocity (Vu) changes, 17 out of the 35 sites available for comparison show changes of one sigma or less. The eight sites which change by more than 3 sigma are listed in Table 5.

Table 4. Differences between NOAA site velocities and NNR-NUVEL-1A (all units mm/yr)

VLBI Site Name	Vn	Ve	Vu	Vn err	Ve err	Vu err	Constraint *
Eurasia:							
TROMSONO	-1.5	11.2	-3.2	1.0	1.0	5.7	
ONSALA60	0.1	-0.8	2.2	0.1	0.2	0.3	CV
TRYSILNO	0.7	-4.7	19.9	1.2	1.1	9.9	
EFLSBERG	0.9	1.4	-1.7	0.2	0.2	0.7	CV
WETTZELL	0.5	0.4	-3.1	0.1	0.2	0.3	CV
DSS65	0.2	0.9	4.3	0.3	0.3	1.1	C
MEDICINA	2.4	2.6	-4.3	0.2	0.3	0.7	
MATERA	5.0	3.5	-6.6	0.3	0.4	1.3	
SESHAN25	-3.7	9.3	-6.0	0.8	1.0	2.6	C
Africa:							
NOTO	-0.8	2.1	-5.6	0.3	0.4	1.4	
HARTRAO	-6.1	-6.1	-1.8	1.1	1.0	1.3	C
N. America, stable:							
HAYSTACK	-0.4	1.2	1.8	0.2	0.2	0.6	
WESTFORD	-0.1	0.9	0.9	0.1	0.2	0.5	CV
ALGOPARK	-0.9	0.9	1.9	0.2	0.2	0.7	CV
MARPOINT	1.0	-1.4	2.3	0.9	0.6	4.5	
GORF7102	2.7	4.1	-10.5	1.0	0.8	5.6	
NRAO_140	-0.1	0.7	0.2	0.2	0.2	0.8	
NRAO85_3	0.3	-0.7	1.7	0.3	0.2	0.8	CV
RICHMOND	0.6	1.3	2.2	0.3	0.2	0.6	CV
HRAS_085	0.8	0.6	1.9	0.3	0.2	0.9	
FD-VLBA	2.6	-2.1	-1.7	0.5	0.4	1.5	
PIETOWN	-1.0	-0.6	-4.5	0.3	0.2	0.9	
LA-VLBA	1.5	0.5	-2.9	0.3	0.3	1.0	
PLATTVIL	-1.5	0.4	-3.9	0.6	0.4	3.5	CV
YLOW7296	-1.6	3.0	19.1	0.7	0.7	2.9	
GILCREEK	-1.3	0.5	-0.8	0.1	0.2	0.4	CV
N. America, California:							
MOJAVE12	7.6	-3.4	-1.7	0.2	0.2	0.7	C
GOLDVENU	6.2	-2.7	-5.8	0.5	0.4	2.1	
DSS15	6.4	-5.1	-4.1	0.7	0.5	2.1	
OVRO_130	8.2	-5.2	-0.6	0.3	0.2	1.1	C
HATCREEK	4.6	-6.1	-1.1	0.3	0.3	1.2	
S. America:							
SANTIA12	17.4	16.7	-5.1	2.4	2.1	6.3	
Pacific:							
VNDNBERG	-1.4	-0.6	4.6	0.3	0.2	1.1	C
KAUAI	1.7	-3.5	0.2	0.3	0.5	0.6	CV
MARCUS	1.8	-0.7	-1.6	2.3	2.0	8.1	
KWAJAL26	-2.4	-2.1	-4.7	1.7	1.4	6.0	C
Australia:							
DSS45	0.6	1.3	8.8	1.1	1.5	1.6	C
HOBART26	2.0	1.4	4.5	1.2	1.6	1.7	C
Japan (N. America):							
KASHIMA	2.7	-10.1	-4.5	0.4	0.6	0.7	C
KASHIM34	2.0	-8.9	-16.4	0.7	0.9	2.0	

* `C' indicates site used in coordinate origin constraint; `V' indicates inclusion in frame velocity constraint. Adjacent sites are indicated by indentation of second and third site names of each group.

Table 5. NOAA Vu changes > 3 sigma

VLBI Site Name	Vu change (1994-1993) (mm/yr)	(sigmas)	Vu change due to NMF (mm/yr)
PIETOWN	+17.9	12.8	+7.1
LA-VLBA	+11.6	5.5	+2.8
HATCREEK	+9.5	4.5	+0.8
VNDNBERG	+7.1	3.6	+1.0
MATERA	+7.8	3.5	+2.1
DSS45	-8.6	3.4	-0.1
KASHIMA	-3.3	3.3	-1.6
MOJAVE12	+3.1	3.1	+0.8

Some of these changes can probably be attributed to the addition of significant new data sets. HATCREEK, VNDNBERG, and MOJAVE12 were involved in many of the 234 western U.S. mobile sessions which were added to our solution for the first time this year. The increase in number of observations for these three stations was 303%, 246%, and 39%, respectively. While the volume of new data for MOJAVE12 is not as great, most of the new sessions occurred during the early history of the station. MATERA and LA-VLBA also have substantially more data than last year, by 122% and 88%, respectively. Significantly, many of the new sessions involving these stations, and KASHIMA as well, used very large networks especially well suited for determining three-dimensional velocity components. Some of the change in the vertical velocity estimates can be attributed to the use this year of the NMF tropospheric refraction model, which does not rely on real-time surface met data collected at the sites. The effect of this change is listed in the rightmost column of Table 5. It is most significant for PIETOWN, for which some early sessions do not have met data. The NMF model also accounts for part of the Vu changes at LA-VLBA, MATERA, and KASHIMA.

Based on these considerations, we expect the velocity values reported here to be reasonably accurate measures of the actual long-term motions of most of the VLBI sites relative to one another. The uncertainty in the net systematic motion of the terrestrial frame itself is probably much larger, as much as 2-4 mm/yr. The formal velocity uncertainties reported here do not include a component to account for such systematic effects. The uncertainties are likely to be somewhat optimistic although probably by a factor less than two in most cases, based on the distribution of Vu changes from last year to this year. Recently, Watkins *et al.* [1994] showed that VLBI and SLR horizontal velocities for a set of 10 sites agree within 2-3 mm/yr with a reduced chi-squared of 1.7. On the other hand, Herring and Dong [1991] and others have noted apparently non-linear length changes for several baselines. In any event, there are a few sites listed in Table 4 whose estimated motions do not appear reliable even allowing for overly optimistic formal errors. Tromso, Norway (TROMSONO) is the most obvious example with a eastward motion 11 mm/yr greater than predicted by NNR-NUVEL-1A. However, this velocity result is based entirely upon two mobile VLBI occupations of the site separated in time by three years with four sessions per occupation. Unfortunately, only one of the four sessions in the first occupation (in summer 1989) used a geometrically robust network, while the remaining three sessions involved only two other sites. There is, therefore, effectively no redundancy in the TROMSONO velocity determination. Any systematic error associated with the single strong session of the first occupation, such as an error in the eccentricity vector measurement, will be absorbed entirely and undetectably into the velocity estimate. On the other hand, a large displacement of the local site or monument cannot be excluded. The possibilities cannot be distinguished without additional observational data. The inferred horizontal motions for GORF7102 (GSFC, MD, USA) and YLOW7296 (Yellowknife, NWT, Canada) of a few mm/yr level are also suspect. Both of these sites rely on the combination of data from two different monuments with non-overlapping observing histories. The GSFC site has data from 1989.4-1992.5 at monument 7102 and 1993.3-present at 7108; Yellowknife was observed from 1984.7-1985.7 at monument 7285 before operations were shifted to a new installation (monument 7296) in 1991.5. In addition, the FD-VLBA site at Ft. Davis (TX, USA) shows motions greater than 2 mm/yr in both horizontal components, significant at the 5-sigma level. This may simply be an instance of an immature determination: while there is a substantial amount of data for FD-VLBA (40 sessions, most of which involve geometrically robust networks) its history began in 1992.5 providing a span of only about 1.5 years.

Apart from the specific exceptions discussed above, the results presented in Table 4 are generally in excellent agreement with the NNR-NUVEL-1A global plate motion model or indicate tectonic deformations. In Europe, the horizontal motions among ONSALA, EFLSBERG, WETTZELL, and DSS65 suggest the rigidity over that part of the Eurasian plate to be better than 2 mm/yr. SESHAN25 (Shanghai, China), near the far eastern egde of the plate, appears to be moving with respect to the plate by about 10.0 mm/yr at azimuth 112 degrees. While this magnitude agrees with that of Robaudo and Harrison [1993], who interpret Shanghai motion to be an effect of Philippine plate subduction, the direction of our velocity residual is nearly opposite to theirs (azimuth 314 degrees). Their analysis included both VLBI and SLR data but we can offer no explanation for this large discrepancy. Both Italian penisula sites show significant non-plate motions, especially MATERA which is observed to move at a rate of 6.1 mm/yr at azimuth 55 degrees relative to the model. Deformation is expected in this region due to collision of Africa with Eurasia. The Sicilian site of NOTO, assigned to the African plate, is consistent with the model except for a moderate residual motion of 2.1 mm/yr eastward. On the other hand, HARTRAO in South Africa displays a SW residual of 8.6 mm/yr. This site does lie within a broad region of suspected deformation.

There are 10 sites in N. America outside the western deformation zone with horizontal motion determinations having formal uncertainties of 0.3 mm/yr or less. Among these, the velocity residuals fall within -1.3 to +1.5 mm/yr in the north direction (weighted rms is 0.9 mm/yr) and within -0.7 to +1.3 mm/yr in the east (weighted rms is 0.8 mm/yr), suggesting a plate rigidity of about 3 mm/yr or better over distances exceeding 6000 km. Interestingly, the motion of HRAS_085 (at Ft. Davis, TX, USA) is among the closest of all the VLBI sites in agreeing with the plate model. (Note that it not be used in any of the frame constraints.) Numerous investigators have remarked on the apparent non-linear motion of this site [e.g., Herring and Dong,1991]. As is already well established, the sites in California east of the plate boundary all move northwestwardly due to interaction with the adjacent Pacific plate. The results for SANTIA12 (Santiago, Chile), with just over two years of data now available, strongly indicate deformation, presumably associated with the offshore subduction of the Nazca plate beneath S. America. The magnitude of this northeastward motion, about 24.1 mm/yr, compares with a residual velocity of 19mm/yr at azimuth 77 degrees for Arequipa (Peru) reported by Robaudo and Harrison [1993].

Two of the Pacific sites have robust velocity determinations, VNDNBERG on the California coast and KAUAI in the Hawaiian Islands. The magnitude of the non-plate motion at KAUAI -- 3.9 mm/yr at azimuth 296 degrees -- approaches a level of concern because this site is used in our constraint for the motion of the terrestrial frame and its isolated location gives it considerable leverage in the constraint. Closer study of this result is warranted. The velocities for the two Australian sites are in much better agreement with the plate model this year than in our previous report. We attribute this primarily to the adoption of the recalibrated NNR-NUVEL-1A plate model as our reference velocity frame. Nonetheless, the estimated vertical motions, especially for DSS45, remain large enough to be a concern. To some extent, this could be caused by net translational motion of the reference frame, relative to the Earth's center of mass, contributed by the set of velocity constraint sites, which are roughly antipodal to Australia. The westward motions of the two Japanese sites listed in Table 4 show the effect of Pacific plate subduction, as many investigators have discussed.

As we noted in our report last year [Ray *et al.*, 1993], the VLBI vertical rates of motion for very well determined sites in N. America and Europe differ significantly from the rates expected due to post-glacial rebound. Examples are shown in Table 6. In general, the observed differential rates in N. America are smaller than the rates predicted by the ICE-3G model of Tushingham and Peltier [1991] whereas the observed difference between ONSALA and WETTZELL is much larger than predicted. The best agreement is for sites along the east coast of the U.S., where both the measured and predicted differential motions are small. To some extent, the discrepancies could again be due to the inherent ambiguity in the net motion of the terrestrial frame but that is unlikely to account fully for the differences. Mitrovica *et al.* [1993] considered also the horizontal motions expected due to post-glacial rebound and found significant differences compared with VLBI measurements.

Table 6. Observed versus predicted differential uplift rates due to post-glacial rebound (all units mm/yr)

VLBI Sites Name		VLBI uplift difference value	VLBI uplift difference sigma	ICE-3G uplift difference* value
N. Europe:				
ONSALA	- WETTZELL	+5.3	0.4	+1.0
N. America:				
ALGOPARK	- WESTFORD	+1.0	0.9	+4.4
"	- HAYSTACK	+0.1	0.9	+4.4
"	- NRAO85_3	+0.2	1.1	+4.4
"	- NRAO_140	+1.7	1.1	+4.4
"	- RICHMOND	-0.3	0.9	+3.1
"	- GILCREEK	+2.7	0.8	+4.0
WESTFORD	- NRAO85_3	-0.8	0.9	0.0
"	- RICHMOND	-1.3	0.8	-1.3
"	- GILCREEK	+1.7	0.6	-0.4
RICHMOND	- GILCREEK	+3.0	0.7	+0.9

* Post-glacial rebound rates are from the ICE-3G model by Tushingham and Peltier [1991]. Note that the observed VLBI uplift rates are inherently ambiguous due to the net motion of the terrestrial frame.

3.3 Earth Orientation Results:

We reiterate the important change made in our analysis procedures last year, which continues to apply this year: Herring's [1993] model for diurnal and semi-diurnal variations in the polar x and y coordinates and in UT1 is used in our interpolation of a priori EOP values (see description of procedures in section 2). In that sense, the NOAA EOP values report total quantities (except for the nutation offsets which are relative to the IAU 1980 model for nutation). Having accounted for the diurnal and semi-diurnal EOP variations, together with adjusting the EOP offsets at the weighted mean observation epoch of each session, our time series should fully preserve tidally coherent components with periods down to about 12 hours.

Table 7 gives the mean EOP offset values for our series EOP(NOAA) 94 R 01 compared with a solution using last year's analysis procedures and the identical set of 1374 VLBI observing sessions (the 1609 sessions being submitted less the 234 newly added mobile VLBI sesssions less the reference epoch session). The weighted rms scatters about the mean differences are also shown in Table 7 as are the EOP offset values due solely to new values for the reference epoch (from Table 1). It can be seen that the overall offset changes are nearly entirely due to the new reference epoch values, which in turn are predominantly caused by realignment of the IERS system itself as a result of the newest realizations of the terrestrial and celestial reference frames. The total polar motion offset in the x coordinate, however, is about twice the size of the offset in x for the reference epoch (and is about two-thirds the magnitude of the IERS system change in x; see Table 1). These varied x offset values are probably related to the comparatively large rotational difference about the X-axis between the NOAA terrestrial frame and ITRF-92 (see Table 3).

Table 7. Offset changes in NOAA EOP values (1994 - 1993)

	x (mas)	y (mas)	UT1 (ms)	ψ (mas)	ε (mas)
Offsets due to new reference values (from Table 1):					
	-0.1058	+0.2729	+0.075	-0.4155	+0.3053
Total offsets due to all changes:					
wtd. mean	-0.2068	+0.2741	+0.0762	-0.3826	+0.2644
wtd. rms	0.1071	0.1154	0.0055	0.0814	0.0333

3.4 Intensive UT1 Results:

We have previously shown that the accuracy of UT1 determinations from the 1-hour single-baseline IRIS Intensive sessions is about 0.055 ms based on comparison with results from 24-hour VLBI sessions [Ray *et al.*, 1993]. The largest contributor is likely to be error in the a priori calibration of the tropospheric delay, including problems in the collection of meteorological data from the stations. The character of this error source should be random if changes in local weather dominate the variation and systematic if there are discrete biases in the met data or in the tropospheric refraction models. The IERS Central Bureau [IERS,1993] has reported applying systematic corrections to the Intensive UT1 to remove effects associated with quarterly changes in the observing program. (The Intensive schedule is held fixed in local sidereal time for three-month periods.) The corrections range from -0.120 to +0.080 ms. Our own analysis confirms the existence of such quarterly biases, however, the magnitudes are generally much smaller -- typically +/- 0.020 ms or smaller with a few excursions up to about 0.040 ms; the third quarter of 1987 was exceptional with a bias of about -0.090 ms. These biases are probably caused by non-pointlike brightness structures in many of the radio sources that have been used for the Intensive observations. For example, 3C273B was used until late 1987. Even since the shift to less complex sources beginning in 1988, the magnitude of known source structure effects could easily account for UT1 biases at the level of 0.020 ms. Other possible sources of bias, such as offsets in the station met data, are more difficult to estimate without assessments of reasonable magnitudes for such offsets.

4. Electronic Access

On behalf of the International Radio Interferometric Surveying (IRIS) joint subcommission of the International Association of Geodesy (IAG) and the Committee on Space Research (COSPAR), NOAA distributes the monthly IRIS Bulletin A, "Earth Orientation Bulletin", and maintains electronic files containing the same data on the NOAA computers which can be accessed by outside users. The data files described here, as well as the operational EOP data files updated weekly and others, are available through Internet using the `ftp' file transfer protocols. The Internet node where the files can be retrieved is `ray.grdl.noaa.gov' at IP address `140.90.159.197'. The user should login as `anonymous' and reply with the user's name when asked for a password. After logging into the system, the user should change to the appropriate subdirectory by issuing the command `cd dist/vlbi' and use the ftp `get' command to transfer the appropriate files. A README file in that directory provides explanatory information.

Acknowledgements. We thank Arthur Niell of Haystack Observatory for providing code to implement the NMF troposphere mapping function.

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Summary description of the solutions NOAA 94 R 01 and 94 R 02

1 - Technique:
Bandwidth-synthesis Mark III 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 - Solution ID:
solution rundate = 9/ 3/94 20:39:59

4 - Software Used:
COREL and FRNGE for the Mark III data correlation; DE200 ephemerides, CALC-7.6, and SOLVE-3 for data analysis

5 - Relativity Scale:
Radio source coordinates are in solar system barycentric system;
Terrestrial site coordinates are geocentric (ignoring the local gravitational potential of the Earth)

6 - Permanent Tidal Correction on Station:
No correction is applied to remove the zero-frequency displacement introduced by the solid Earth tide model.

7 - Tectonic Plate Model:
NNR-NUVEL-1A is used to specify the large-scale motion of the entire terrestrial reference frame in both translational and rotational senses for 10 VLBI sites (see text for details); the same model is also used to propagate the relative positions of sites with data spans too brief to permit reliable determinations of VLBI velocities.

8 - Velocity of Light:
299 792 458. m/s

9 - Geogravitational Constant:
not applicable

10 - Reference Epochs:
Station coordinates -- 1988 January 01
Source coordinates -- J2000.0
EOP fixed epoch -- 1991 August 12 19:49:50 UT

11 - Adjusted Parameters:
XYZ geocentric station coordinates and linear station velocities adjusted globally for all sites at their mean observation epochs; radio source coordinates adjusted globally for all sources; pole x and y coordinates, UT1, nutation longitude and obliquity offsets adjusted for each 24-hour observing

session; UT1 is the only EOP adjusted for 1-hour Intensive sessions; clock polynomial coefficients adjusted for all but one station in each observing session; atmosphere offset parameters for each hour interval for each station for each 24-hour observing session (no atmosphere parameters are included in the analysis of the 1-hour Intensive sessions)

12 - Definition of the Origin:

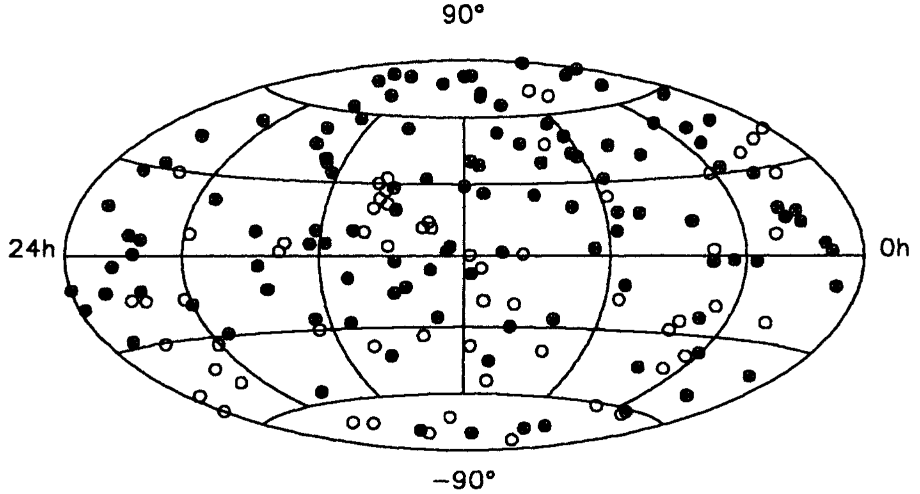
The coordinate origin of the terrestrial reference frame is specified by setting the vector sum of the adjusted coordinates for 20 VLBI sites equal to the corresponding vector sum for ITRF-92 (see text); the right ascension origin of the celestial reference frame is specified by setting the sum of the adjusted right ascensions for 71 radio sources, each weighted by the cosine of its declination, equal to the corresponding sum for ICRF-92 (see text)

13 - Definition of the Orientation:

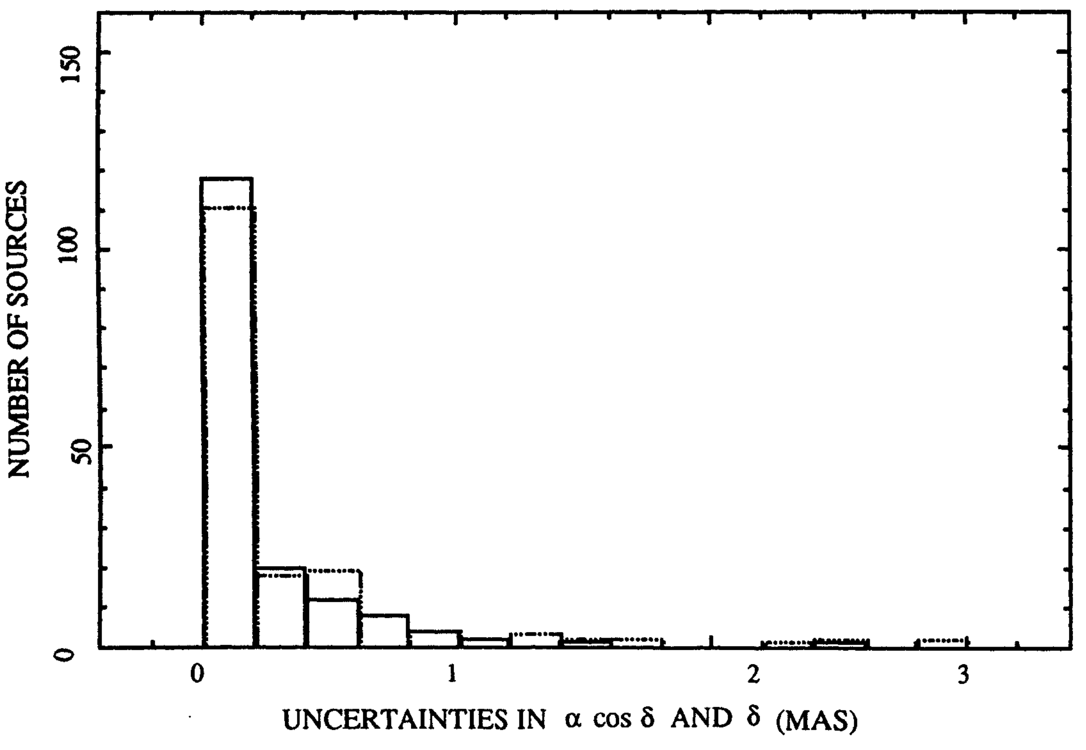
The relative orientation of the terrestrial and celestial reference frames is specified by fixing the EOP values to those interpolated from the EOP(IERS)90C04 series (corrected for the offsets and drift rates reported by the IERS to give consistency with the ITRF-92 and ICRF-92 frames) plus the diurnal and semi-diurnal contribution for x, y, and UT1 computed by the model of Herring [1993] for the reference epoch 1991 August 12 19:49:50.

14 - Constraint for Time Evolution:

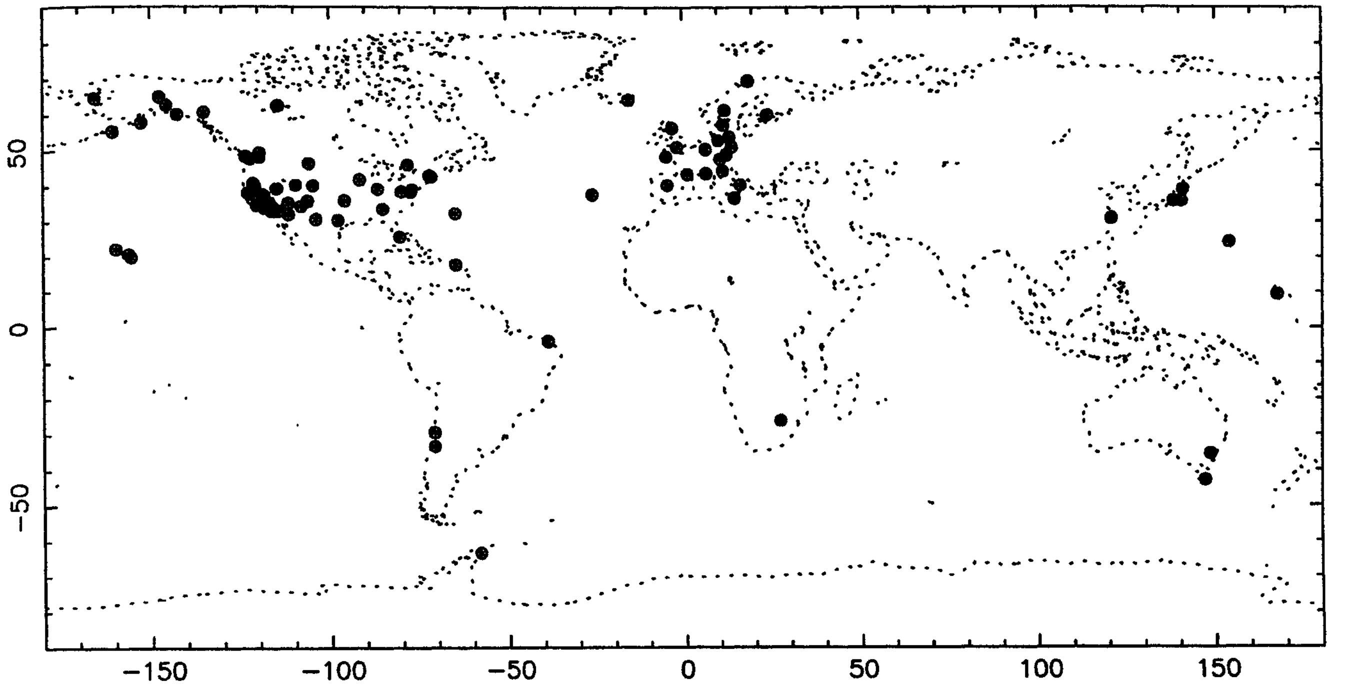
The secular translational velocity and rotational velocity of the terrestrial reference frame are specified through constraints; see item 7 above and text.



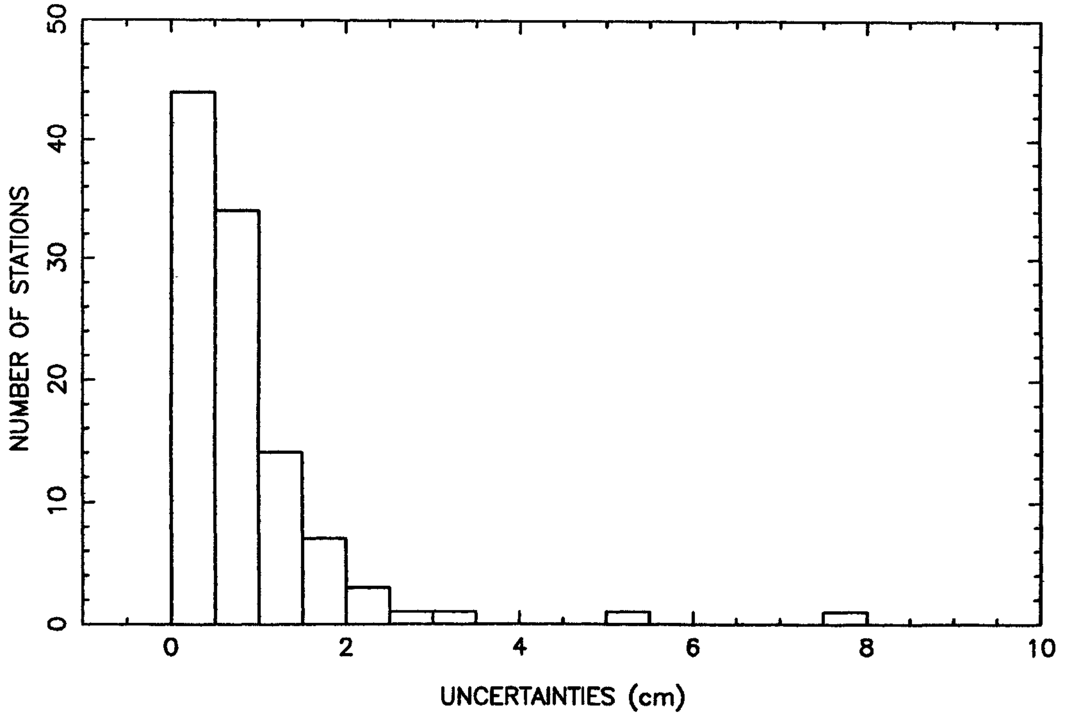
Distribution over the sky of the 176 extragalactic radio sources of the celestial frame RSC(NOAA) 94 R 01. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(NOAA) 94 R 01. 10 radio sources with uncertainties larger than 0.003" are not shown.



Distribution of the 91 sites of the terrestrial frame SSC(NOAA) 94 R 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 106 stations of the terrestrial frame SSC(NOAA) 93 R 01.

EOP(NOAA) 94 R 01 From Sep 1980 to May 1994

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	0.63	16	0.67	16	0.31	16	0.98	16	0.33
1981	6	1.00	6	1.14	6	0.57	6	1.33	6	0.46
1982	10	1.10	10	0.98	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	0.70	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	158	0.39	158	0.39	158	0.20	158	0.53	158	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	0.35	218	0.14
1993	165	0.16	165	0.15	165	0.07	165	0.28	165	0.12
1994	21	0.14	21	0.13	21	0.05	21	0.25	21	0.10

EOP(NOAA) 94 R 02 From Apr 1984 to May 1994

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

YEAR	UT1	
	Nb	Sigma
1984	64	0.74
1985	159	0.42
1986	237	0.43
1987	245	0.42
1988	255	0.42
1989	234	0.43
1990	261	0.43
1991	247	0.41
1992	223	0.30
1993	260	0.29
1994	82	0.30

ANALYSIS OF THE IRIS VLBI INTENSIVE SESSIONS EOP(OPA) 93 R 02

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The series is based on the analysis of VLBI observations obtained on the Wettzell-Westford baseline in the frame work of the IRIS program. 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) 93 C 03 and the NNR-NUVEL1 model for the terrestrial frame, RSC(IERS) 93 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 1992 IERS Annual Report, p. II-17).

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) 93 R 02 — From Jan 1992 to May 1994

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

YEAR	UT1	
	Nb	Sigma
1992	211	0.20
1993	259	0.16
1994	83	0.17

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

USNO 94 R 03

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Abstract. As part of its participation in the National Earth Orientation Service (NEOS) the U.S. Naval Observatory (USNO) operates a program in Very Long Baseline Interferometry (VLBI) data acquisition and analysis to monitor changes in the orientation of the Earth on a regular basis. Starting with this annual report the operational USNO VLBI solution will include all available multiple baseline dual frequency VLBI data. The changes in the USNO VLBI data analysis system required to use the expanded data set will be described in this report, along with the resulting Navy 1994-3 reference frame and USNO/NEOS VLBI observing program during the past year.

1. Introduction

The Navy VLBI Network (NAVNET) measures the orientation of the Earth in space from Mark III VLBI observations. In the past the operational USNO VLBI reference frame and data reduction were based only on data acquired by the NAVNET and NEOS programs. In 1993, a large fraction of the world-wide collection of VLBI data from other observing programs was imported into the USNO VLBI analysis system from the Goddard Space Flight Center and, beginning in May 1994, the operational solution includes data from all sources. This large data set, with data back to 1979, requires considerable changes in the way operational VLBI solutions are performed and, in particular, the adoption of an empirically determined station velocity model, replacing the previously used NUVEL model based on geological information.

These data are used to estimate UT1, polar motion and nutation for inclusion in the International Earth Rotation Service (IERS) combined solutions. All of the currently available multiple baseline VLBI data are provided in this report in a uniform reduction using the Navy 1994-3 reference frame.

Section 2 of this report describes the USNO VLBI observing program for Earth orientation. Section 3 provides information about the USNO VLBI data analysis procedures and the Navy 1994-3 reference frame used in the operational VLBI data reduction process, while section 4 describes the VLBI data products available from the USNO Earth orientation program.

2. Data Acquisition by the USNO VLBI Earth Orientation Program

The NEOS is a joint cooperative effort of the USNO and the National Oceanic and Atmospheric Administration (NOAA), and the NAVNET VLBI program was initiated to complement the observations coordinated by the NOAA as part of the International Radio Interferometric Surveying (IRIS) subcommission. The USNO VLBI program began observations in June, 1987, with a series of 8-hour GNUT (Goddard-Navy UT) experiments. Routine NAVNET observations began on January 5, 1989, on a weekly basis using antennas in Maryland, Alaska, Hawaii and Florida. One 24-hour GNUT was observed in September, 1988; monthly 24-hour NAVNETs commenced in April, 1989, and all of the weekly NAVNETs were nominally 24 hours in duration starting June 27, 1989. After the successful establishment of routine NAVNET operations, NAVNET and IRIS-A operations were coordinated starting in May, 1991, with there being one IRIS-A session on Monday/Tuesday, and one NAVNET session on Thursday/Friday, of every week. With the loss of the Richmond station in Hurricane Andrew on August 24, 1992, the NAVNET was reduced to only three stations (Alaska, Hawaii and Green Bank), and it was decided to combine IRIS-A and NAVNET operations into a weekly NEOS-A observing session, with the last NAVNET being NAVNET-226 on April 29/30th, 1993. The addition of the European IRIS-A station to the NEOS-A network provided the redundancy missing from the NAVNET since the loss of Richmond, together with an improvement in performance over previous NAVNET observations. In order to continue the "just in time" system of scheduling and processing observing sessions as quickly as possible to meet the weekly Thursday morning deadline for Earth orientation data, the start of the weekly runs were moved from 1800 UTC on Thursday to 1800 UTC on Tuesday. This change in start times makes it possible for the VLBI tapes from Germany and Brazil to be at the Washington Correlator on Monday morning at the latest, and thus for correlation and processing to be completed by Wednesday evening in time for the Thursday deadline.

Current NEOS operations, starting May 5th, 1993, consist of one weekly 24-hour duration NEOS-A observing session per week for Earth orientation. The operational NEOS-A network currently includes the VLBI stations at Gilmore Creek, Alaska, Kokee Park, Hawaii, Wettzell, Germany, Fortaleza, Brazil, and Green Bank, West Virginia. In addition, a monthly NEOS-B session is performed to improve the terrestrial reference frame, and special NAVNET EXperimental (or NAVEX) sessions continue to be observed on an irregular basis. The complete list of stations that have participated in the operational and experimental USNO Earth orientation VLBI program are given in Table 1.

The NEOS-A network was extended in the summer of 1993 to include 2 new VLBI stations, in Hawaii and Brazil. The new 20 meter VLBI antenna (site name KOKEE) constructed by the USNO at the Kokee Park Geophysical Observatory (KPGO), saw first light on May 28th, 1993, and conducted its first VLBI observations (three sources for a fringe test) on June 3rd, 1993. Strong fringes were detected immediately upon receipt of the tapes at the Washington Correlator at the USNO on June 4th, 1993. The first geodetic observations conducted by this antenna were during the NEOS-A-6 observing session (June 8/9), and the KOKEE antenna began routine VLBI observations as the primary KPGO antenna with NEOS-A-9 (June 29/30). In general, good results have been obtained from the new KOKEE antenna, with the new system being about a factor of 2.4 times as sensitive as the old, so that Signal to Noise Ratios (SNRs) for a similar length scan are larger by about that factor (or the same SNR can be obtained with about 1/5th the integration time), and this improvement in sensitivity is reflected in lower postfit residual scatters for the new system compared to the old. Continued system tests and special experiments were conducted using the KOKEE antenna (together with the older 9 meter KAUAI antenna at the site) through the summer of 1993, after which the KAUAI system was placed on reserve status. The 9 meter KAUAI antenna was reactivated for the CONT'94 period, and was used for another set of joint observations with the KOKEE antenna between 12 January and 14 March, 1994.

Another addition to the NEOS-A network came with the development of a new VLBI site in Fortaleza, Brazil (site name FORTLEZA). This 14.2 meter antenna, originally part of the connected element interferometer operated by the USNO at Green Bank, West Virginia, was moved to a site outside Eusebio, a suburb near Fortaleza, Brazil, through the combined efforts of INPE (the Brazilian Space Agency) and NOAA, and is operated by INPE. The first use of this antenna in the NEOS-A network was in NEOS-A-10 (July 6 and 7th, 1993), and it continues to participate on a weekly basis.

Table 1 : Stations Participating in the U.S. Navy VLBI Program to date

Station	Location	Station ID Code
GILCREEK	Fairbanks, Alaska	AL
KAUAI	Kokee Park, Kauai, Hawaii (9 meter)	KU
KOKEE	Kokee Park, Kauai, Hawaii (20 meter)	KK
RICHMOND	Richmond, Florida	RI
NRAO85 3	Green Bank, West Virginia	GB
MARPOINT	Maryland Point, Maryland	MD
MOJAVE12	Mojave, California	MO
WESTFORD	Westford, Massachussetts	WF
ALGOPARK	Algonquin Park, Canada	AP
MEDICINA	Medicina, Italy	ME
NOTO	Noto, Italy	NO
MATERA	Matera, Italy	MA
HARTRAO	Hartebeesthoek R.A.O., South Africa	HT
WETTZELL	Wettzell, Germany	WZ
SANTIA12	Santiago, Chile	ST
KASHIM34	Kashima, Japan (34 meter)	KB
KASHIMA	Kashima, Japan (26 meter)	KA
HOBART26	Hobart, Tasmania	HO
ONSALA60	Onsala, Sweden	O6
FORTLEZA	Fortaleza, Brazel	FT
MIZNAO10	Mizusawa, Japan	MN

In cooperation with the Agenzia Spaziale Italizana, Centro di Geodesia Spaziale, the NAVNET program initiated, in October, 1991, a series of monthly NAVNET experimental (NAVEX) observing sessions using the new geodetic antenna in Matera, Italy, along with the Alaska, Hawaii and West Virginia NAVNET stations. Radio telescopes in Wettzell, Germany, Noto, Italy, Algonquin Park, Canada, Hartebeesthoek, South Africa, Santiago, Chile, Hobart, Tasmania, and Kashima, Japan, have also participated in NAVEX observations. The major goals of these experiments are to study sources of systematic error in VLBI Earth orientation measurements and to investigate high-frequency (sub-diurnal) variations in orientation. To facilitate these goals these experiments are performed simultaneously with IRIS-A or IRIS-P experiments conducted by the U.S. National Geodetic Survey. During the EPOCH'92 campaign (July 27th - August 11th, 1992) the USNO complemented the nearly continuous Extended Research and Development sessions conducted by the NASA/GSFC VLBI group by organizing a set of 4 NAVEX-Global sessions using Green Bank, Matera, Algonquin Park, Hartebeesthoek, Santiago and Kashima. NAVEX observations using this network, without Santiago, but plus the Gilmore Creek, Kokee and Hobart antennas, continued on a once every other month basis in 1993. These large (8 to 10 station) global NAVEX experiments, which are in general not simultaneous with other VLBI sessions, are intended to study the benefits obtained from the operation of large global networks, in addition to continuing the study of systematic errors and sub-diurnal variations in the VLBI data. Two northern hemisphere NAVEX sessions were conducted during 1993 simultaneously with independent NOAA VLBI observing sessions to continue the simultaneous observing program at a reduced level.

The NAVNET VLBI data are acquired using Mark III VLBI data acquisition terminals with a nominal 8 X band and 6 S band channels, each with a 2 MHz bandwidth, measuring group delay and phase delay rate. The accuracy of the group delay estimates is greatly improved by using the technique of band width synthesis. Until the beginning of 1992 normal operation used channels spread across 85 MHz at S band and 350 MHz at X band, using the "NARROW" channel frequencies shown in Table 2. In 1991 the potential spanned bandwidth was nearly doubled and operational use of the "WIDE" spanned bandwidth shown in Table 2 began on February 1, 1992. Not all antenna feed systems can adequately handle the complete WIDE bandwidth shown in Table 2, and the "NEOS WIDE" channel frequencies shown in Table 2 were developed to use the wider bandwidth subject to these feed limitations. At present, the operational NEOS-A observing sessions nominally use the NEOS WIDE bandwidth setup, and the NAVEX sessions, the NARROW bandwidth setup. In order to investigate possible systematic differences between the narrow and wide frequency assignments, the NEOS-A schedules started alternating between three sessions with NARROW channel assignments, and three with NEOS WIDE channel assignments, starting with NEOS-A-31 (30th November, 1993), which was a NEOS WIDE schedule. This alternation of schedules is intended to continue for one year.

A series of Mark III Mode-A double speed experiments on June 2nd, August 25th and September 16th of 1993 were used to observe the Supernova SN1993J and other weak radio sources that need the increased sensitivity available with Mode-A observations. It is expected that Mode-A double speed experiments (which use both the upper and lower side bands of each VLBI channel for a total channel bandwidth of 8 MegaHz) will continue on an occasional basis in 1994.

Table 2 : NEOS Channel Frequencies

Channel Number	Band	NARROW Band Frequency Setup, MHz	WIDE Band Frequency Setup, MHz	New NEOS WIDE Frequency Setup, MHz
1	S	2217.99	2220.99	2212.99
2	S	2222.99	2230.99	2222.99
3	S	2237.99	2250.99	2257.99
4	S	2267.99	2305.99	2297.99
5	S	2292.99	2340.99	2317.99
6	S	2302.99	2345.99	2322.99
1	X	8210.99	8212.99	8182.99
2	X	8220.99	8252.99	8222.99
3	X	8250.99	8352.99	8422.99
4	X	8310.99	8512.99	8562.99
5	X	8420.99	8732.99	8682.99
6	X	8500.99	8852.99	8782.99
7	X	8550.99	8912.99	8842.99
8	X	8570.99	8932.99	8862.99

The NAVNET VLBI data are correlated at the Washington Correlator, which is located at the Naval Observatory and run by a consortium among the USNO, NOAA, NRL, and NASA. The correlator provides estimates of the band-width-synthesis group delay and the phase delay rate from the radio noise recorded at the stations, together with estimates of the random (thermal) noise associated with each measurement and a quality factor describing the reliability of the measurement. Only observations with quality factors of 5 or higher are used in the USNO reduction of the NAVNET data. Observations with letter quality factors of A through F, which indicate serious problems with the correlated data, are also not used in the USNO reduction.

3. Data Analysis by the USNO VLBI Earth Orientation Program

After correlation, fringe fitting, and the removal of any remaining bandwidth synthesis delay ambiguities, data from all available mutiple baseline VLBI sessions with durations of 16 hours or longer are used in a series of weighted least-squares solutions to define a USNO VLBI reference frame and to estimate the Earth orientation within that reference frame. This is a considerable change from previous years, when only USNO acquired VLBI data were used in the USNO VLBI Annual Report, and a empirical station velocity model had to be adopted in order to adequately model the tectonic motion of the stations over the 14 years of available data.

The USNO Earth orientation program data reduction depends on a reference frame, which is derived from VLBI data and is intended to align the resulting Earth orientation determinations as closely as possible with both the terrestrial and celestial reference frames maintained by the IERS. Due to software limitations, the USNO VLBI celestial reference frame is obtained from the available VLBI data in a two solution process. In the first solution, the IERS Rapid Service (Bulletin A) estimates of the UT1 and polar motion are treated as a priori measurements and the nutation in longitude and obliquity is fixed at the IERS Rapid Service values. The mean of the Right Ascensions of the 79 radio sources given in Table 3 is held fixed at the value given in the IERS combined celestial reference frame from the 1992 Annual Report (RSC(IERS) 93 C 01), and all other source coordinate parameters are adjusted in this solution. The purpose of this first solution is to align the celestial reference frame with the celestial pole implied by the IERS Rapid Service nutation series. The declinations of two sources, 0229+131 and OJ287, are then fixed in a second solution to the values obtained in the first solution. This second solution globally adjusts all other source coordinates (subject to the same Right Ascension constraint as before). The IERS Rapid Service estimates of the UT1 and polar motion are treated as a priori measurements in this solution, and the nutation offsets are adjusted freely. Seven radio sources (3C273B 3C345 3C454.3 3C84 1117+146 1031+567 1947+079) were judged to have too much source structure to be usable for geodetic work to have repeatable positions. The coordinates of these "removed" sources are treated as "arc" parameters in the 1994-3 solution, and in the operational Earth orientation solutions, in that a separate position is estimated for each observing session in which they appear. Six other sources (CL4 0218+35A 0218+35B 1830-21A 1830-21B 0218+357) were judged to have such structure that they could not be used at all; these sources were deleted entirely from all reference frame and operational Earth orientation solutions.

Table 3 : Sources used to constrain Right Ascension in the Navy 94-3 reference frame :

0016+731	0048-097	0119+041	0133+476	0149+218	0201+113	0202+149
0202+319	0212+735	0229+131	0234+285	0300+470	0308-611	NRAO140
0420-014	0420+417	0434-188	0454-234	0458-020	0528+134	0552+398
0637-752	0642+449	0657+172	0727-115	0735+178	0742+103	0745+241
0804+499	0820+560	0823+033	OJ287	0859+470	4C39.25	OK290
0955+476	0954+658	1039+811	1044+719	1055+018	1123+264	1124-186
1144+402	1156+295	1252+119	1308+326	1334-127	1342+663	1354+195
1354-152	OQ208	1502+106	1510-089	1606+106	1611+343	1614+051
1633+38	1656+053	1738+476	1739+522	1741-038	1749+096	1823+568
1954+513	2007+777	2021+614	2021+317	2121+053	2128-123	2136+141
2144+092	2145+067	2201+315	2216-038	CTA102	2234+282	2243-123
2255-282	2355-106					

An empirical station velocity model was adopted for the Navy 1994-3 terrestrial reference frame. The translation degeneracy in station positions was removed by fixing the mean value for the positions of 15 stations (Table 4) to the values provided by the ITRF-92. The translation degeneracy in station velocities was removed by fixing the mean value for the velocities of the same 15 stations to those predicted by the Nuvel tectonic motion model.

A number of stations did not have enough data to meaningfully estimate tectonic motion rates, but were close to another VLBI station which did have sufficient data. The velocity estimates for these stations were constrained to be the same; the list of constrained stations is given in Table 5. Other sets of nearby stations with sufficient data to provide independent station motion estimates were not constrained in this fashion. A few other stations were allowed to have episodic motion due to nearby earthquakes causing seismic motions. These "episodic" stations have two position estimates, one from before and one after the earthquake, and are given in Table 6, together with the date of the earthquake. The seismic motion was assumed to be instantaneous, and the same tectonic rate was assumed to apply before and after the step function change at the time of the earthquake.

Table 4 : Stations used to constrain the station position and velocity origin in the 1994-3 reference frame.

ALGOPARK	DSS65	GILCREEK	HARTRAO	HOBART26	KAUAI
KWAJAL26	MEDICINA	NOTO	ONSALA60	PIETOWN	RICHMOND
VNDNBERG	WESTFORD	WETTZELL			

Table 5 : Stations with velocity ties in the 1994-3 reference frame. Stations within each pair of parenthesis were constrained to share the same station velocity adjustments in the 1994-3 solution.

```
( MOJAVE12 GOLDVENU DSS15 )
( KASHIMA  KASHIM34 )
( NRAO85_1 NRAO85_3 )
( KOKEE    KAUAI    )
( DSS65    ROBLED32 )
( OV_VLBA  OVRO_130 )
( GGAO7108 GORF7102 )
( YELLOWKN YLOW7296 )
```

Table 6 : Stations with episodic motions (step function changes at a specified time) in the 1994-3 reference frame.

Station Name	Date of Motion
YAKATAGA	871201
SOURDOGH	871201
KODIAK	871201
WHTHORSE	871201
FORTORDS	891001
PRESIDIO	891001
DSS15	920627
GOLDVENU	920627
MOJAVE12	920627

The data used in the report are processed with IERS standard models to the maximum extent possible (see summary description at the end of this report), with the GSFC CALC 7.6 software being used throughout in the data reduction process. The CFA 2.2 tropospheric mapping function is used to relate line of sight tropospheric propagation delays to the tropospheric zenith delay, and an elevation angle lower limit of 7 degrees is used in all solutions. The IERS standard model for both horizontal and vertical deformations due to ocean tidal loading is applied, although ground deformations due to atmospheric loading are currently not modeled. The reference time adopted was January 1, 1988.

Unmodeled variations in the tropospheric propagation delays and the relative time offset between the station clocks are a significant source of error in geodetic VLBI. The surface pressure, temperature and relative humidity are recorded at each station and used to estimate the variations in the hydrostatic zenith tropospheric propagation delay. Further variations in these quantities are treated by the estimation of piecewise linear models directly in the least squares solutions. A new piecewise linear function is introduced every 60 minutes for the zenith tropospheric propagation and every 90 minutes for the relative station clocks.

The new USNO Navy reference frame, Navy 1994-3, was prepared using 991,841 delay and delay rate observation pairs from 1578 observing sessions (complete through March 15, 1994), with a weighted rms residual scatter of 36.6 picoseconds for the delay observations and 90.0 femtoseconds per second for the delay rate data. The NAVNET station coordinates (at epoch 1988 January 1) and velocities from the reference frame solution have been submitted to the IERS Central Bureau as well as the corresponding source positions. Some stations did not have enough data to meaningfully estimate station velocities. For these stations the Nuvel model was used without adjustment; the velocity error entries in the station velocity table are blank for these stations.

The Navy 1994-3 reference frame is the operational reference frame used in the operational USNO Earth orientation solutions. The intention is to provide an a priori reference frame good at the level of 0.25 millisecond of arc. In order to do this, sources with position uncertainties in the 1994-3 frame less than 0.25 milliarcseconds (mas), and stations with position formal errors of 5 millimeters or less are fixed to the 1994-3 values without adjustment. These stations and sources are provided in Tables 7 and 8, respectively. The positions of the other sources, and the positions and velocities of any other stations, are estimated in the operational solutions.

Table 7 : Stations used without adjustment in the Operational Earth orientation solutions

ALGOPARK	DSS45	DSS65	EFLSBERG	FD-VLBA	GILCREEK
HARTRAO	HATCREEK	HAYSTACK	HOBART26	HRAS_085	KASHIM34
KASHIMA	KAUAI	KOKEE	LA-VLBA	MARPOINT	MATERA
MEDICINA	NOTO	NRAO_140	NRAO85_3	NRAO85_1	ONSALA60
OVRO_130	PIETOWN	PLATTVIL	RICHMOND	SESHAN25	TRYSILNO
VNDNBERG	WESTFORD	WETTZELL			

Table 8 : Sources used without adjustment in the Operational Earth orientation solutions

0014+813	0016+731	0048-097	0059+581	0104-408	0106+013
0119+041	0133+476	0201+113	0202+149	0208-512	0212+735
4C67.05	0229+131	0234+285	0235+164	0256+075	0300+470
0308-611	NRAO140	CTA26	NRAO150	0402-362	0420-014
0434-188	0438-436	0454-810	0454-234	0458-020	0528+134
0537-441	0552+398	0637-752	0642+449	0657+172	0716+714
0727-115	0735+178	0738+313	0742+103	0745+241	0804+499
0805+410	0814+425	0820+560	0823+033	OJ287	0859+470
0919-260	0917+624	4C39.25	OK290	0955+476	0954+658
1034-293	1038+52A	1039+811	1044+719	1053+704	1053+815
1055+018	1057-797	1104-445	1123+264	1124-186	1128+385
1144+402	1145-071	1150+812	1156+295	1219+044	1244-255
1251-713	3C279	1308+326	1334-127	1351-018	1354+195
1354-152	1357+769	1402+044	OQ208	1418+546	1424-418
1502+106	1510-089	1519-273	1548+056	1549-790	1606+106
1611+343	1614+051	1610-771	1622-253	1633+38	1637+574
NRAO512	1642+690	1705+018	1726+455	NRAO530	1739+522
1741-038	1745+624	1749+096	1803+784	1815-553	1823+568
1831-771	1921-293	1923+210	1928+738	1954+513	1958-179
2007+777	3C418	2113+293	2121+053	2128-123	2134+00
2136+141	2144+092	2145+067	2155-152	VR422201	2201+315
2216-038	CTA102	2234+282	2243-123	2255-282	2345-167
2355-106					

The NAVNET/NEOS Earth orientation results submitted to the IERS Central Bureau are obtained from the 24-hour experiments in a multi-parameter least squares adjustment for UT1, polar motion and both components of nutation, together with the piecewise linear clock and troposphere models. Additional baseline dependent clock offsets are added whenever the non-closure of the clock estimates around station triangles is judged to be significant. We have discovered that errors in the a priori UT1 rate during an observing session can be significant, especially given the typical rapid turn around of the NEOS data, as experiments are frequently processed using UT1 predictions. The operational USNO solutions now estimate the rate of change of the UT1 averaged over the entire observing session; the UT1 rate estimates from that solution are converted into estimates of the variation in the Length of Day (LOD). The reporting epoch for each observing session is the mid-point of the session, defined as the mean of the time of the first and the last observations in the session. The station coordinates and source positions for the stations and sources in Tables 7 and 8 are fixed at the a priori values given by the Navy 1994-3 reference frame; the positions of the other sources and stations are estimated in the Earth orientation solution. The tie to the 1994-3 reference frame is thus obtained by the fixed station coordinates and source positions; this method avoids week to week variations in the reference frame used in the reduction of the NAVNET data. Although the Earth orientation parameter formal errors thus do not fully reflect errors introduced by uncertainties in the station coordinates and source positions, solutions performed without these constraints indicate that inclusion of these errors would not significantly increase the resulting Earth orientation parameter formal errors. The solution provided to the IERS Central Bureau used a total of 1,028,262 observation pairs (delay and delay rate) from 1606 sessions and produced weighted rms residual scatters of 36.4 picoseconds for the delay observations and 90.3 femtoseconds per second for the delay rate data. (This solution included experiments from 1994 which were not used in the reference frame solution.)

The USNO has conducted a series of 2 and 3 hour duration observing sessions, known as NAVNET INTensives, or NAVINTs, to investigate the determination of UT1 and Polar Motion from short duration experiments. These observing sessions nominally involve 3 stations, GILCREEK and KAUAI (or KOKEE) together with either RICHMOND or NRAO85_3, although a few 4 station sessions have been observed. The UT1 and Polar Motion estimates from the multiple baseline NAVINTs were also provided to the IERS Central Bureau. A total of 4161 observation pairs (delay and delay rate) from 120 observing sessions were used in this solution, with the total weighted rms residual scatter being ± 33.5 picoseconds for the delay data and 70.6 femtoseconds per second for the rate data. One difference between the NAVINT solutions and the 24-hour experiment solutions lies in the treatment of nutation. The nutation is not estimated in the NAVINT solutions, but is instead held fixed to the values given in the IERS Bulletin A, linearly interpolated to the epoch of the experiment. As in the long duration solutions, the station coordinates and source positions are fixed at the a priori values given by the Navy 1994-3 reference frame, and the reporting epoch for each observing session is the mid-point of the session.

The current accuracy of VLBI Earth orientation results is sufficient to clearly detect tidally coherent diurnal and semi-diurnal variations in UT1 and polar motion, mostly due to the non-linear response of the oceans to the luni-solar gravitational tides. These tidally forced variations can be a significant source of systematic error, and so have been removed from the 1994-3 reference frame solutions and Earth orientation solutions using the empirical model of T.A. Herring [*Proceedings of the COSPAR World Space Congress, Adv. Space Res.*, **13**, 281-290, 1993]. The model values were not added back into the UT1 and polar motion estimates, so that the orientation results provided in the long-duration solutions (and in the operational Earth orientation solutions) are close to the 24-hour average values for the Earth orientation centered on the epoch of observation. The model values are also not added back into the NAVINT results; these short duration estimates thus do not reflect the true orientation at the reporting epoch, but are instead closer to the 24-hour average for the reporting epoch.

4. Data Available from the USNO VLBI Earth Orientation Program

Earth orientation results from the USNO VLBI solutions are distributed in the form of three tables. The first table contains the Earth orientation data in the format requested by the IERS Central Bureau, and includes the Earth orientation parameter values and their formal errors together with the weighted root mean square delay error, the experiment duration, the number of delay observations, and a subset of the Earth orientation parameter correlation matrix.

The errors presented in this report are formal errors obtained from the covariance matrix of the least squares adjustment. The post fit residual scatter is always larger than would be expected given the formal error estimates for the delay and delay rate observables provided by the correlator. The total residual scatter is made to agree with that expected given the observable error estimates through addition of empirically determined "noise" additive variances to the square of the correlator formal error estimates. These additive variances are determined separately for each experiment; different constants are used for the delay and delay rate data from each baseline used in an experiment. The second table presents the full covariance matrix for each 24-hour experiment in the form of parameter sigmas and all ten correlation coefficients between the five Earth orientation parameters. Note that the parameter formal errors have all been scaled to milliseconds of arc on the ground or in the sky, so that the relative ability to determine these parameters can be ascertained easily. A list of the stations participating in the experiments is also included in that table.

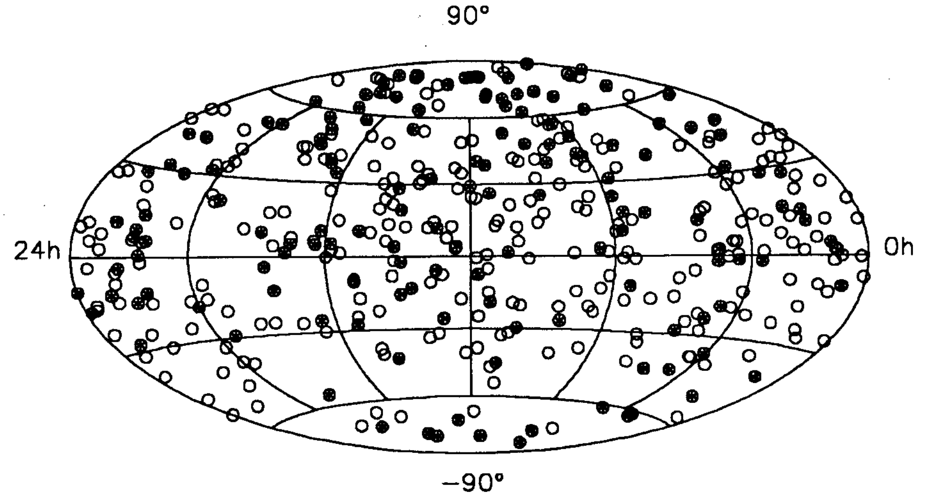
The operational NAVNET solutions now estimate the rate of change of the UT1 during each experiment. These UT1 rate estimates are comparable in accuracy to those obtainable through differencing of successive UT1 offset estimates, and thus make an interesting data product in themselves. The third EOP table contains these UT1 rate estimates, converted to estimates of the Length of the Day (LOD) during the observing session (the LOD is minus the UT1 rate in milliseconds/day).

USNO VLBI data are available by anonymous ftp from casa.usno.navy.mil, or by mosaic from http: //maia.usno.navy.mil. The operational Earth orientation solutions are updated weekly; please contact the USNO to be placed on the list for automatic notification of future updates.

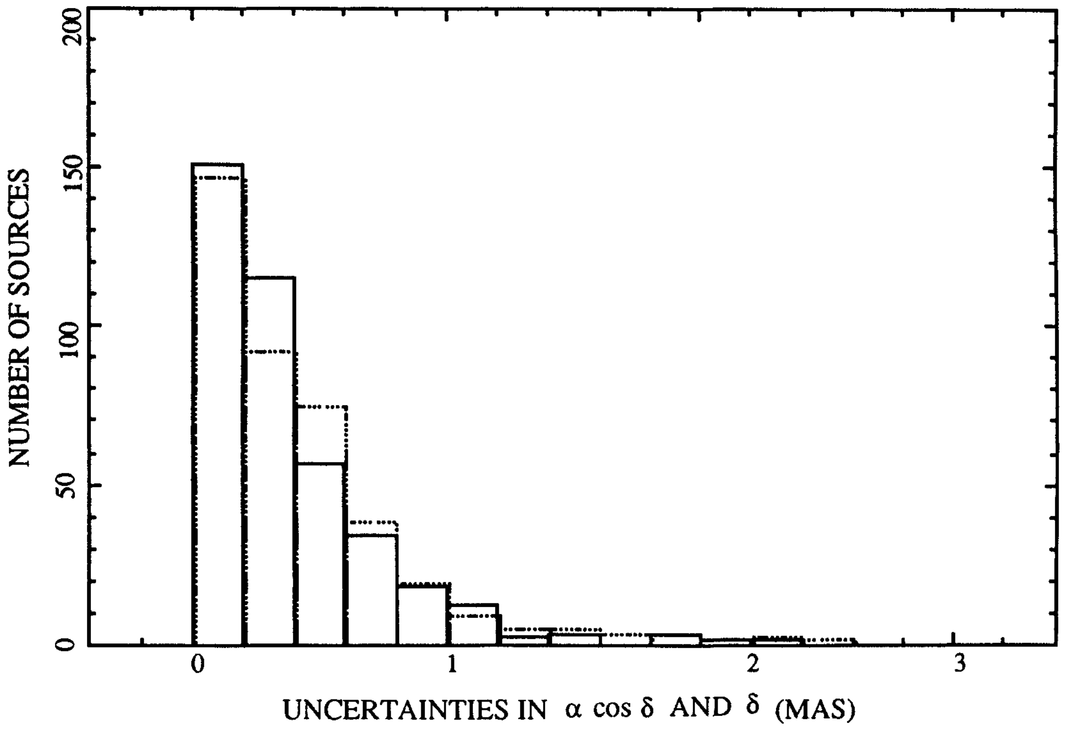
Questions, comments or requests to be placed on the NAVNET distribution list should be directed to T.M. Eubanks, Code TSEO, U.S. Naval Observatory, Washington D.C. 20392-5100, by phone at (202) 653-1501, on SPAN at USNO01::TME, and on Internet at tme@usno01.usno.navy.mil or tme@casa.usno.navy.mil.

Summary description of solution USNO 94 R 03 (USNO 1994-3)

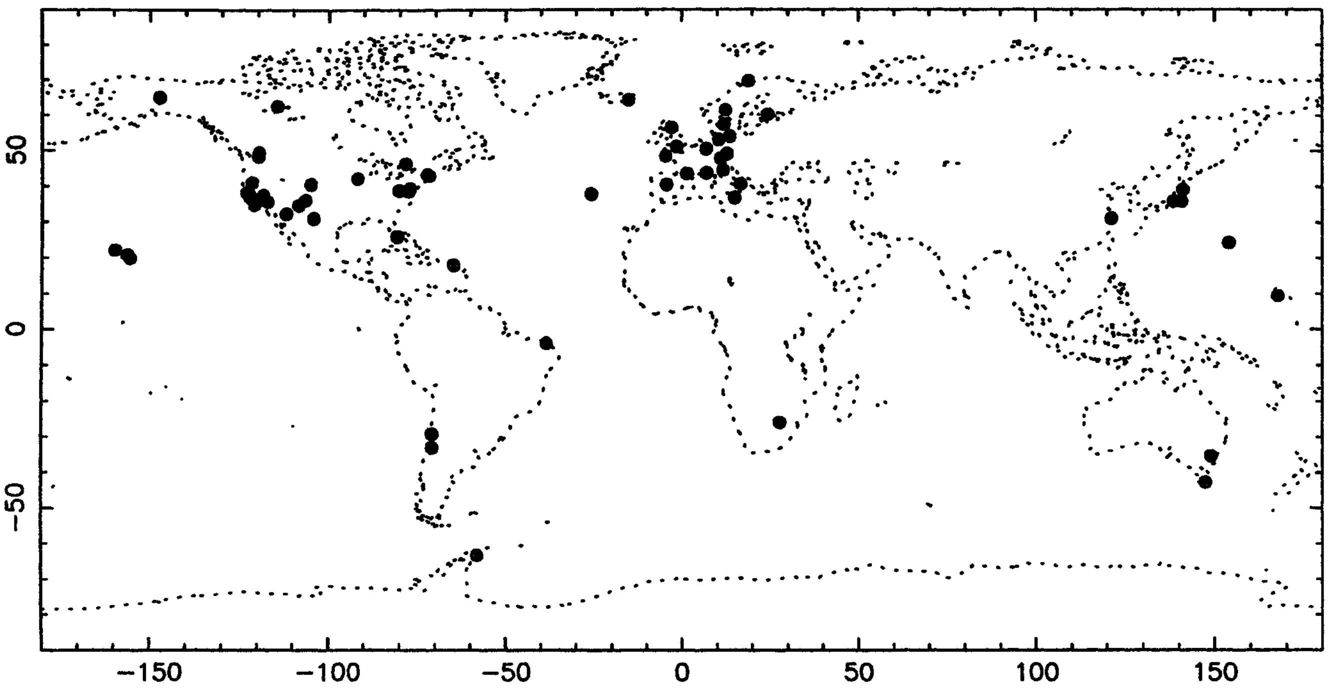
1 - Technique	VLBI
2 - Analysis Center	USNO
3 - Solution identifier	1994-3
4 - Software used	Calc 7.6
5 - Relativity scale	Geocentric
6 - Permanent tidal correction	No
7 - Tectonic plate model	1994-3 empirical model
8 - Velocity of light	299 792 458 m/s
10 - Reference epoch	1 January 1988
11 - Adjusted parameters	see text
12 - Definition of the origin	Mean of 15 station positions in ITRF-92
13 - Definition of the orientation	Mean 79 sources in Right Ascension, Mean IERS Bull. A values for UT1, Polar Motion and (indirectly) Nutation
14 - Constraint for time evolution	Mean of 15 station velocities with the Nuvel model as a priori



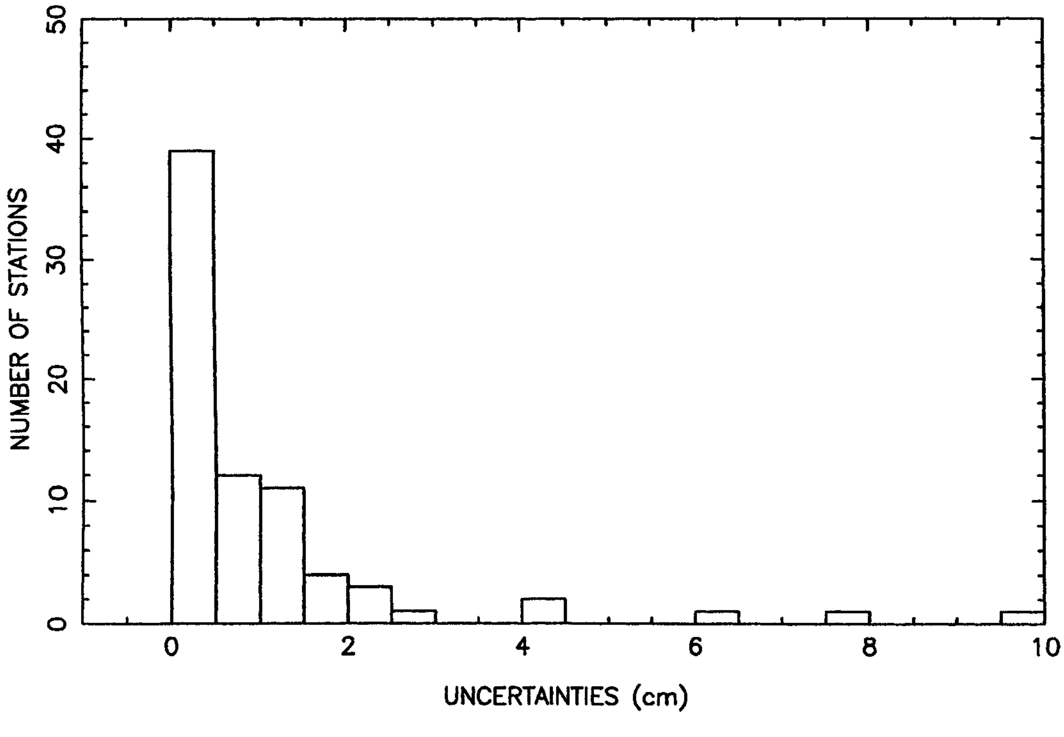
Distribution over the sky of the 411 extragalactic radio sources of the celestial frame RSC(USNO) 94 R 03. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(USNO) 94 R 01. 13 radio sources with uncertainties larger than 0.003" are not shown.



Distribution of the 61 sites of the terrestrial frame SSC(USNO) 94 R 03.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 76 stations of the terrestrial frame SSC(USNO) 94 R 03. 1 station with uncertainty larger than 10 cm is not shown.

EOP(USNO) 94 R 03 From Aug 1979 to May 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
1979	2	1.04	2	1.82	2	0.69	2	1.63	2	0.72
1980	19	0.51	19	0.52	19	0.25	19	0.84	19	0.41
1981	7	0.73	7	1.23	7	0.50	7	0.95	7	0.52
1982	16	0.75	16	0.74	16	0.34	16	1.34	16	0.55
1983	17	1.05	17	1.95	17	0.72	17	1.99	17	0.71
1984	87	0.53	87	0.54	87	0.29	87	0.88	87	0.38
1985	92	0.34	92	0.34	92	0.19	92	0.57	92	0.25
1986	107	0.34	107	0.31	107	0.18	107	0.53	107	0.23
1987	136	0.33	136	0.30	136	0.17	136	0.49	136	0.22
1988	134	0.26	134	0.26	134	0.14	134	0.42	134	0.17
1989	166	0.22	166	0.21	166	0.11	166	0.38	166	0.15
1990	203	0.20	203	0.20	203	0.10	203	0.34	203	0.14
1991	200	0.17	200	0.16	200	0.08	200	0.31	200	0.12
1992	224	0.15	224	0.16	224	0.07	224	0.27	224	0.12
1993	152	0.12	152	0.11	152	0.05	152	0.22	152	0.09
1994	41	0.10	41	0.08	41	0.04	41	0.18	41	0.07

LUNAR LASER RANGING

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

FSG 94 M 01

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

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

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

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

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

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

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

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

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

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

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

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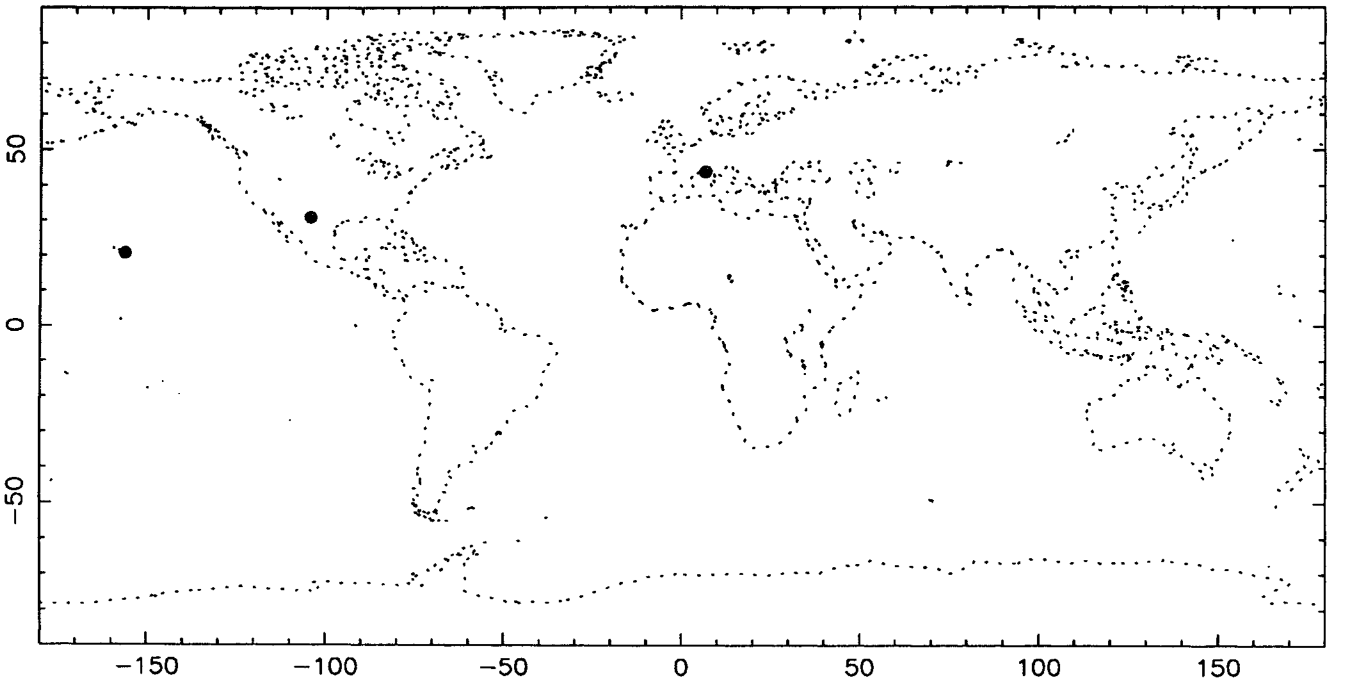
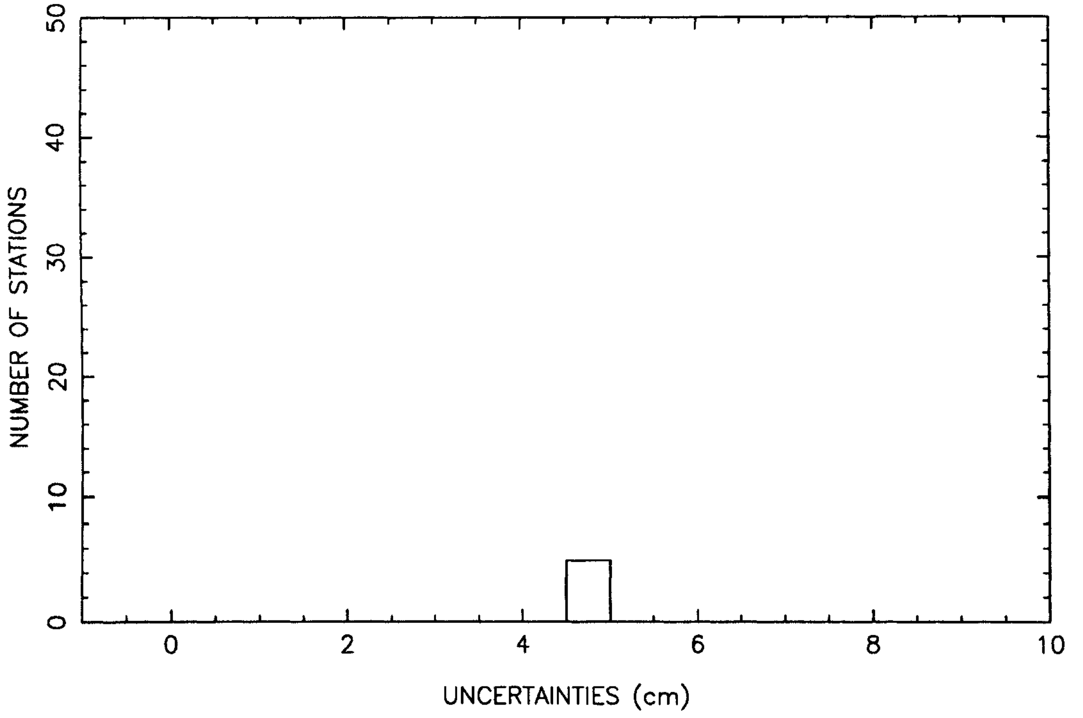
Summary description of the terrestrial system attached to the set of station coordinates SSC(FSG) 94 M 01

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



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



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

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

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

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

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

JPL 94 M 01

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(Contact: LOGOS::JGW or JGW@LOGOS.JPL.NASA.GOV)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Acknowledgments. We wish to acknowledge and thank the staffs of CERGA, Haleakala, the University of Texas McDonald Observatory, and the Lunar Laser Ranging associates. Normal points were constructed from individual photon returns by R. Ricklefs, P. Shelus, A. Whipple, and J. Ries at the University of Texas for the MLRS and for Haleakala data. D. O'Gara produced Haleakala normal points independently. C. Veillet provided normal points for the CERGA data. The planetary ephemeris was produced by E.M. Standish. This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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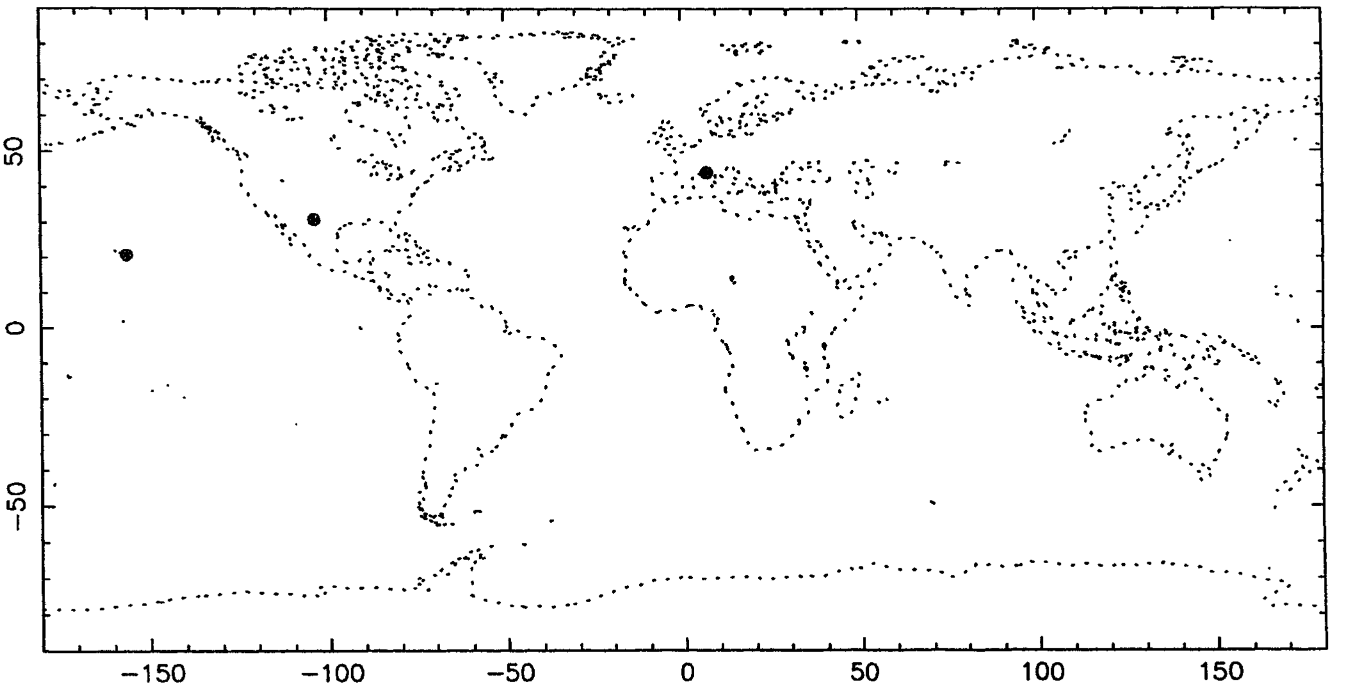
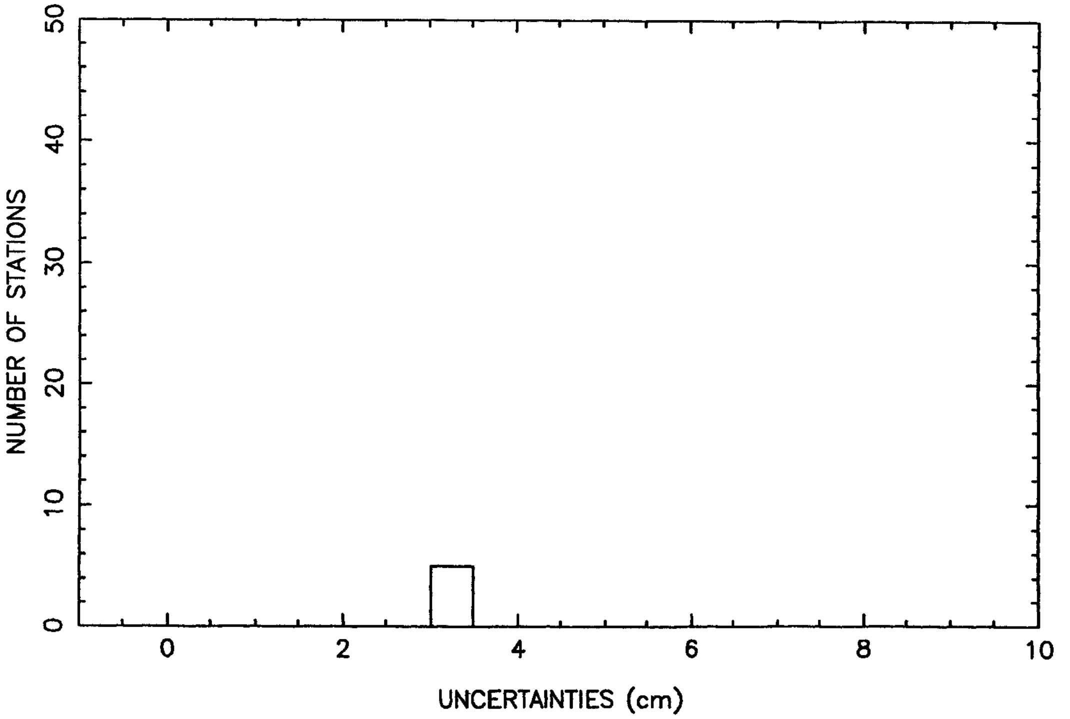
Summary sheet for the description of the terrestrial system attached to the set of station coordinates SSC (JPL) 94 M 01

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



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



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

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

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

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

DETERMINATION OF UNIVERSAL TIME BY LUNAR LASER RANGING

SHA 94 M 01

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

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

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

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

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

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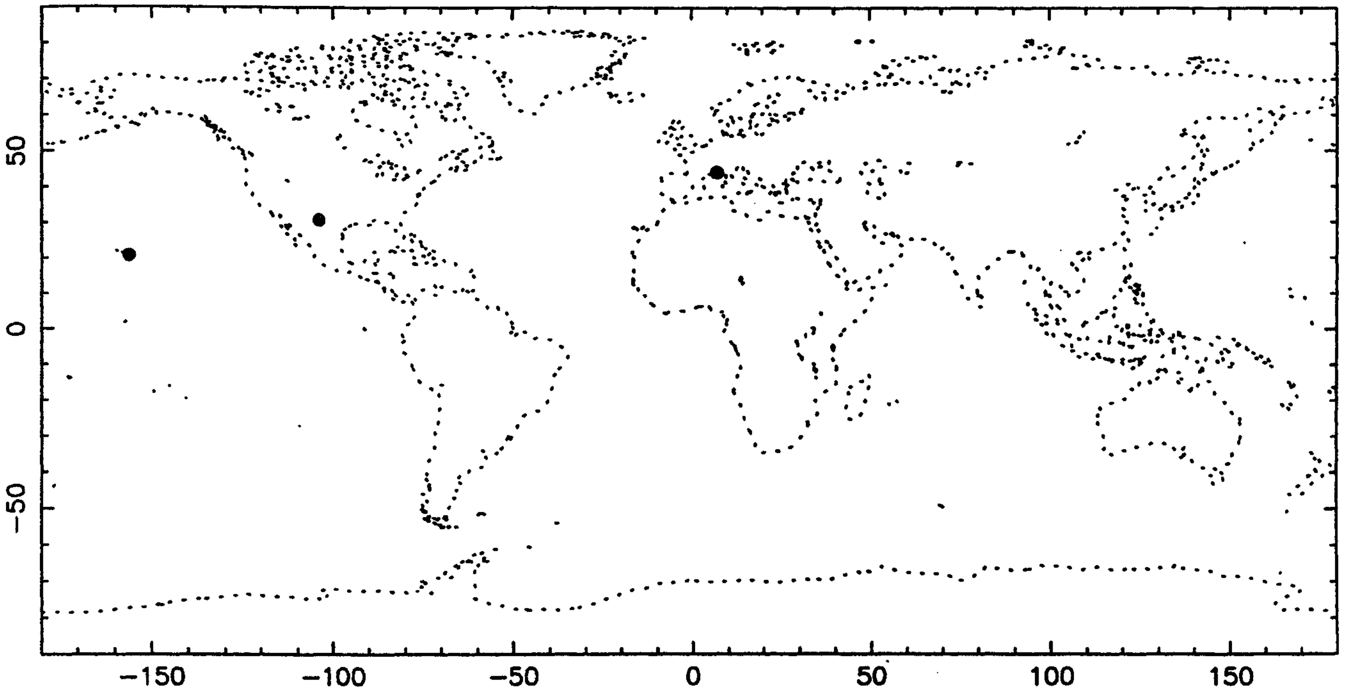
Summary description of the terrestrial system attached to the set of station coordinates SSC(SHA) 94 M 01

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



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

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

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

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

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

UTXMO 94 M 01

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

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

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

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

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

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

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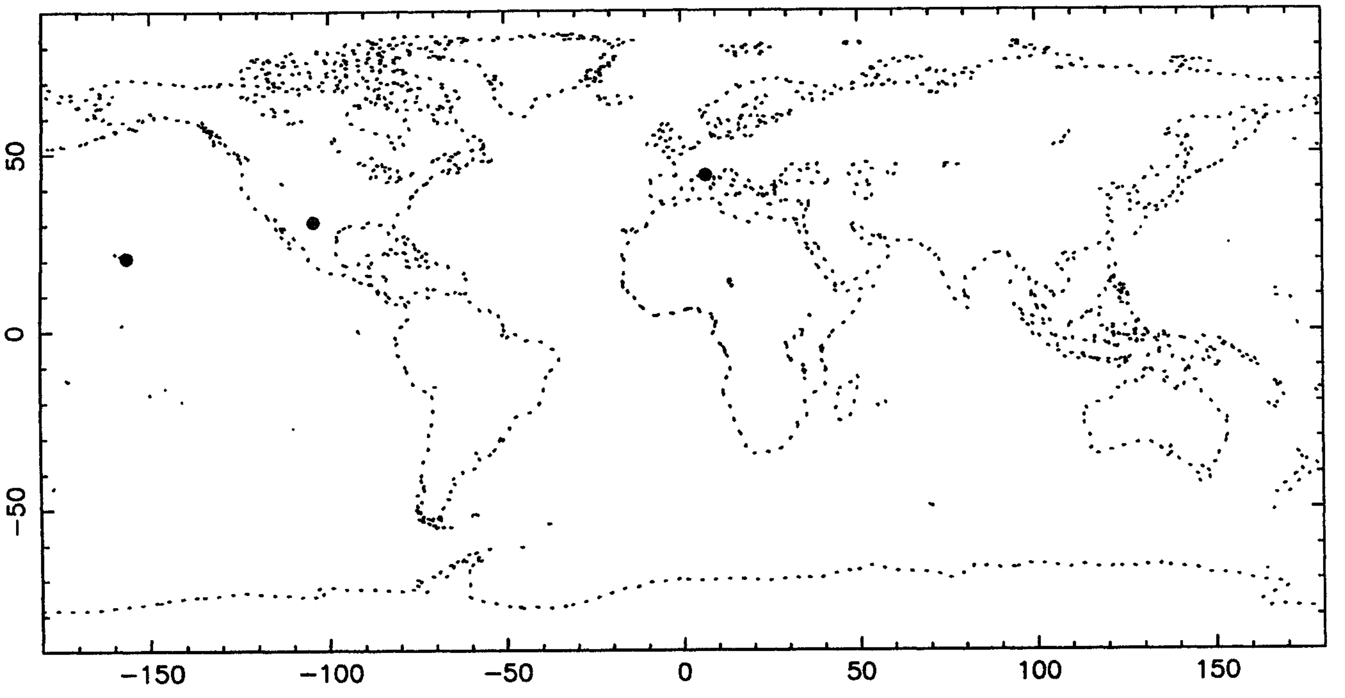
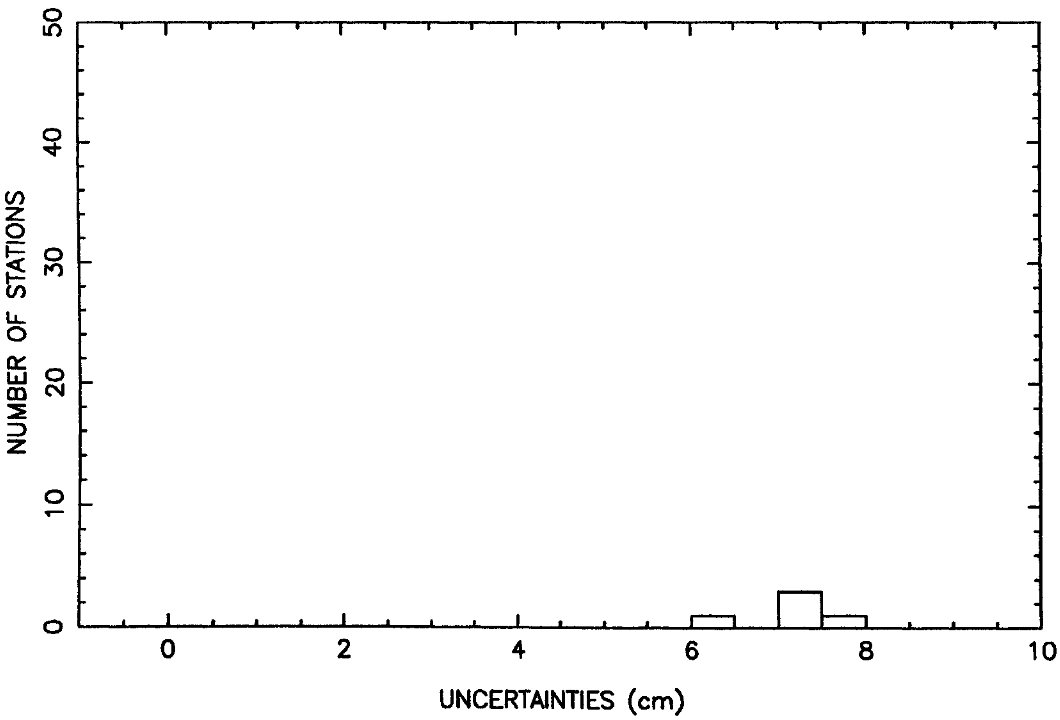
Summary description of the terrestrial system attached to the set of station coordinates SSC(UTXMO) 94 M 01

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



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



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

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

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

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

GLOBAL POSITIONING SYSTEM

ANNUAL REPORT OF THE CODE ANALYSIS CENTER FOR 1993

EOP(CODE) 94 P 02, P 03
SSC(CODE) 94 P 01, 02

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1. Introduction

CODE (the Center for Orbit Determination in Europe) is one of at present seven processing centers of the International GPS Service for Geodynamics (IGS). CODE is a collaboration of

- the Swiss Federal Office of Topography (L+T),
- the French Institut Geographique National (IGN),
- the German Institute for Applied Geodesy (IfAG), and
- the Astronomical Institute of the University of Berne (AIUB)

The processing center is located at the AIUB. The computations originally were performed on a cluster of VAX computers. During 1993 most of these VAX machines were replaced by ALPHA processors, one being reserved for IGS processing only (the other ALPHAs and VAXes are also used for other projects of the institute or by other institutes of the university of Berne). The Bernese GPS Software Version 3.5+ is used for processing. The "+" indicates that this version is in constant development to meet the requirements of a steadily growing workload of the routine processing (Table 1).

Table 1. Workload of the daily "three-days" CODE solutions

Solution Characteristic	DATE (mm yyyy) 06 1992	01 1993	06 1993	12 1993
Number of Satellites	19	21	23	26
Number of Stations	25	28	33	38
Number of Observations	50'000	60'000	110'000	180'000
Number of Parameter	2000	2300	4700	6200

The contribution of CODE to the IGS started on 21 June 1992. There are uninterrupted series of orbits, earth rotation parameters (ERPs), and station coordinates available from CODE since that time. To the best of our knowledge there never were delays longer than about two weeks before our products could be made available to the scientific community.

According to our 1992 annual report delivered to the IERS the emphasis in 1993 should be "on the critical analysis of the physical models and on the development of long-term analysis capabilities". Actually we focused our development and test activities on (1) the orbit model, (2) the stacking of normal equation systems to compute e.g. free network solutions (and the associated velocity field), (3) the optimization of ERP estimation. The progress made in these fields and initial results are summarized in the following sections.

In 1992 the CODE results were significantly affected by AS (Anti-Spoofing). This was due to a mal-functioning (under AS) of the principal receiver in the network. The problem was fixed around the end of 1992; only minor difficulties were encountered in our processing of AS data since that time. We had the impression that the overall performance of the IGS network was satisfactory in 1993. Since 31 January 1994 AS seems to be turned on permanently. It is still difficult to say how much the quality of our results is influenced by AS. At present we believe that the "damage" is of the order of 10% except for the coordinates of stations in the auroral zone, which, at some times, had to be excluded from our routine processing due to the receiver problems.

2. CODE Analysis Characteristics

The general characteristics of our processing were given in Beutler *et al.* (1993b). Here we focus on the changes and the progress made since that time. Detailed information may be found in Rothacher *et al.* (1993), Brockmann *et al.* (1993), Mervart *et al.* (1993), and Beutler *et al.* (1993a).

AUTOMATIC PROCEDURES AT CODE

The processing scheme was modified several times during 1993. At present we proceed as follows: At regular intervals of a few hours an automatic procedure checks whether the data of the day to be processed are available at CODE (sent by IGN) or at the closest IGS Global Data Center. If this is the case, processing of the day is started. In a first step the data are translated from RINEX to the internal (binary) Bernese format. Inconsistencies (wrong file names, wrong station names, "new" antenna heights) are sorted out. This step may need user interaction. Then the pre-processing (single-difference formation, code processing, phase-cleaning) is done with the best orbit information available at that time; today this is usually a one-day extrapolation of our latest three-days solution (see below). Then a first one-day solution is produced. The primary result is a first improved orbit. Afterwards the phase pre-processing is repeated (with this improved orbit) and this time all cycle-slips should be safely removed. If this is not possible, new ambiguities are set up. The principal difference between AS and non-AS processing resides in the number of ambiguities which have to be set up in this step. Again a one-day solution, this time including the estimation of earth rotation parameters is performed. If the solution is acceptable the next three-days solution (Figure 1) is produced in two iteration steps. Two iteration steps are required to guarantee not to run into linearity problems.

```
---------------------------------------------------------------------------
          I----IxxxxI----I                        3-days arc No 1
               I----IxxxxI----I                   3-days arc No 2
                    I----IxxxxI----I              3-days arc No 3
                              .....                      ....

        -------IxxxxIxxxxIxxxxIxxxxIxxxxIxxxxI-->  Released CODE Orbits

                day 1                             from arc No 1
                     day 2                        from arc No 2
                          day 3                   from arc No 3
                                ...                      ...
---------------------------------------------------------------------------
```

Figure 1: Processing in Overlapping 3-days Intervals

THE FORCE MODEL

The principal features did not change since 1992 (Beutler *et al.*, 1993b). Two minor, but important improvements concerning the orbit model for the eclipsing satellites took place in 1993: (1) As described in the 1992 Annual Report, the GPS space-crafts which are in deep eclipse theoretically have to rotate very rapidly by 180 deg around the space vehicles' z-axis twice during the revolution. The numerical problems in processing caused by this phenomenon were sorted out once and for all in 1993. There are clear indications, however, that there is a "real" attitude problem of the eclipsing satellites in the first 20 to 30 minutes after they leave the earth's shadow. (2) The pseudo-stochastic orbit model was used for the eclipsing satellites in our routine processing since 14 June 1993. At predetermined times (at present twice per day) impulse-changes are estimated for these satellites. The resulting orbit is continuous, but its first derivative is not. This change was made after several months of extensive tests. A priori constraints are put on these parameters to prevent damage in the case where (almost) no observations of the eclipsing satellites are available.

THE MODEL FOR THE ERPS

Our parameter estimation program allows to model x, y, and UT1-UTC as a series of polynomials of user defined degree where the individual polynomials refer to user defined connected time intervals. So far we always divided the 3-days interval of our "final" solutions into three one-day bins, and modeled each pole component x, y, and UT1-UTC as a polynomial within each bin. Prior to 14 June 1993 a pure offset for each component (polynomial degree = 0) was estimated. Afterwards the polynomial degree 1 was used; in addition we asked the pole coordinates to be continuous at the day-boundaries. So, before the mentioned date we modeled each component of the pole by 3 parameters in every three-days solution, afterwards by 4 (formally 6 parameters (3 x (1 offset + 1 drift per day)). The main reason for this change was to make our estimates compatible with the a priori model for the pole (which is continuous). Therefore, after 14 June 1993, it was possible to iteratively improve the pole coordinates in the final two processing steps (3-days-solutions). We mention that for UT1-UTC we put a heavy weight either on the a priori value of the first day (before 14 June 1993) or on the 0-degree coefficient of the first day (after 14 June 1993). It is thus clear that we are "only" able to determine the first derivative of the UT1-UTC curve.

By integrating the resulting first derivatives of consecutive days it is formally possible to reconstruct UT1-UTC starting from an arbitrary initial value.

STACKING CAPABILITIES

The "interesting part" of the normal equation system (NEQ-systems) of each 3-days solution is stored together with the necessary logistics information in a file for later use. The newly developed program ADDNEQ (Brockmann *et al.*, 1993) is then used to combine as many of these NEQ systems as required to produce consistent sets of station coordinates, pole positions, and satellite orbits. To a certain extent the models may be modified in ADDNEQ: the pole model may e.g. be simplified in ADDNEQ (only one polynomial per pole component over three days), station velocities may be set up, a change from one terrestrial reference frame to the other (e.g. from ITRF 91 to ITRF 92) is possible, "free network solutions" by removing constraints and by introducing system conditions may be produced. The program again generates a correct variance-covariance matrix for the estimated parameters. The NEQ-systems of our three days solutions have been stored every third day since April 1,1993 (doy 091), every day since July 23, 1993 (doy 200).

OUR REALIZATION OF THE ITRF IN 1993.

Table 2 gives the list of tracking stations we kept fixed in our analyses in 1993. The set marked ITRF 91 obviously refers to the International Terrestrial Reference Frame 1991 (Boucher *et al.*, 1992). The coordinates, velocities, and the eccentricities are available in IGS mail No.90. Our orbits and the ERP series from 1 November 1992 to 31 December 1993 delivered to the IGS Global Data Centers (CDDIS, IGN, SIO) are based on this realization of the ITRF reference frame. On 1 January 1994 we switched to the ITRF 92 (Boucher *et al.*, 1993) in our routine processing. From this time onwards our results at CDDIS, IGN, and SIO are based on the set "ITRF 92" of fixed sites in Table 2. We had to change the fixed sites according to the list selected at the 1992 IGS analysis centers workshop (Kouba, 1993, section "Conclusions and Recommendations"). The coordinates, and corresponding velocities may be found in IGS mail No.430, the site eccentricities are stored in the CBIS (Central Bureau Information System; file: localtie.tab). Thanks to the stacking procedure described above it was possible to re-process the larger part of the 1993 solutions using the ITRF 92 coordinate set and the new station list given in Table 2 (see section 3) with program ADDNEQ. In addition we note that the deformations due to the solid earth tides (Mc Carthy, 1992, Chapter 7, eqn. 6) are added when a set of station coordinates is used in our processing.

Table 2. List of Sites kept fixed in 1993 Processing and in 1994.

ITRF 91 Set	ITRF 92 Set
KOSG 13504M002 *)	KOSG 13504M003
MADR 13407S010	MADR 13407S012
TROM 10302M002	TROM 10302M003
WETT 14201S004	WETT 14201M009
ONSA 10402S002	HART 30302M002
ALGO 40104S001	ALGO 40104M002
FAIR 40408S002	FAIR 40408M001
GOLD 40405M013	GOLD 40405S031
KOKB 40424S001	KOKB 40424M004
YELL 40127M001	YELL 40127M003
RCM2 40499M002	SANT 41705M003
CANB 50103S010	TIDB 50103M108
YAR1 50107M001	YAR1 50107M004

*) unconstrained after 23 July 1993.

MISCELLANEOUS MODELLING COMPONENTS

Attempts were made to improve the model for the GPS force field beyond the 1992 IERS standards. For this purpose the program ORBIMP was developed. The program interprets the satellite positions of the daily IGS precise orbit files as (pseudo-) observations. "Long" arcs (up to 14 days) were formed using consecutive IGS orbit files. In particular Colombo's empirical resonance forces, a generalized radiation pressure model, pseudo-stochastic velocity changes, albedo radiation pressure, and the resonance terms of the earth's gravity field were considered as candidate forces. Only the generalized radiation pressure model led to a substantial improvement (Beutler *et al.*, 1993a). It is planned to use this improved force model in the routine processing after further extensive tests in future. The program ORBIMP also may be used to check the orbit quality of different IGS processing centers. It is used at present in the process of IGS orbit combination, see e.g. Kouba (1994), theory in Beutler, Kouba, and Springer (1993).

Mervart *et al.* (1993) showed that the quality of CODE orbits is sufficient to allow ambiguity resolution (wide- and narrow-lane) on the single baseline level with baseline-lengths up to about 1000 km. Ambiguity resolution and a subsequent orbit improvement step will be implemented in the near future into our routine processing.

3. Results

EARTH ROTATION PARAMETERS

Figures 2a and 2b show differences of the x and y components of our pole estimates with respect to the C04 pole SERIES of the IERS Central Bureau. We clearly see a quality improvement of our estimates from originally about 1 mas per coordinate to now about 0.3 mas. The "discontinuity" at the end of 1993 (MJD 49352) marks the transition from the ITRF 91 to the ITRF 92.

Figures 3a and 3b show the length-of-day estimates of the CODE processing center after removing the zonal solid earth tides and the difference between our estimates and those extracted from the IERS C04 ERP series (which is completely independent of our series). These figures clearly prove that GPS is capable of estimating the length-of-day (with a one day resolution) with a precision of about 0.03 msec. We attribute the quality of our estimates to the length of our satellite arcs (three days).

Figures 4a and 4b demonstrate that the set of fixed coordinates used (see Table 2) is important: Both curves show differences between our solutions and the C04-series. They are based in one case on our realization of the ITRF 91, in the other on our realization of the ITRF 92 system. We clearly see the superiority of our ITRF 92 series.

COORDINATES

Two "free network solutions" could be produced using the program ADDNEQ. The NEQ-systems of 91 3-days solutions covering the time period from 1 April 1993 to 31 Dec 1993 were used for this purpose. The solutions' characteristics are given in the summary description below, the station distribution in Figure 5. In the first set of coordinates (A3) the station velocities were constrained to the ITRF 92 values, in the second case (B3) the station velocities are solved for. We are aware of the fact that a nine month time interval is too small to derive reliable station displacements. We include this solution to allow an optimal combination with coordinate series produced by other analysis centers.

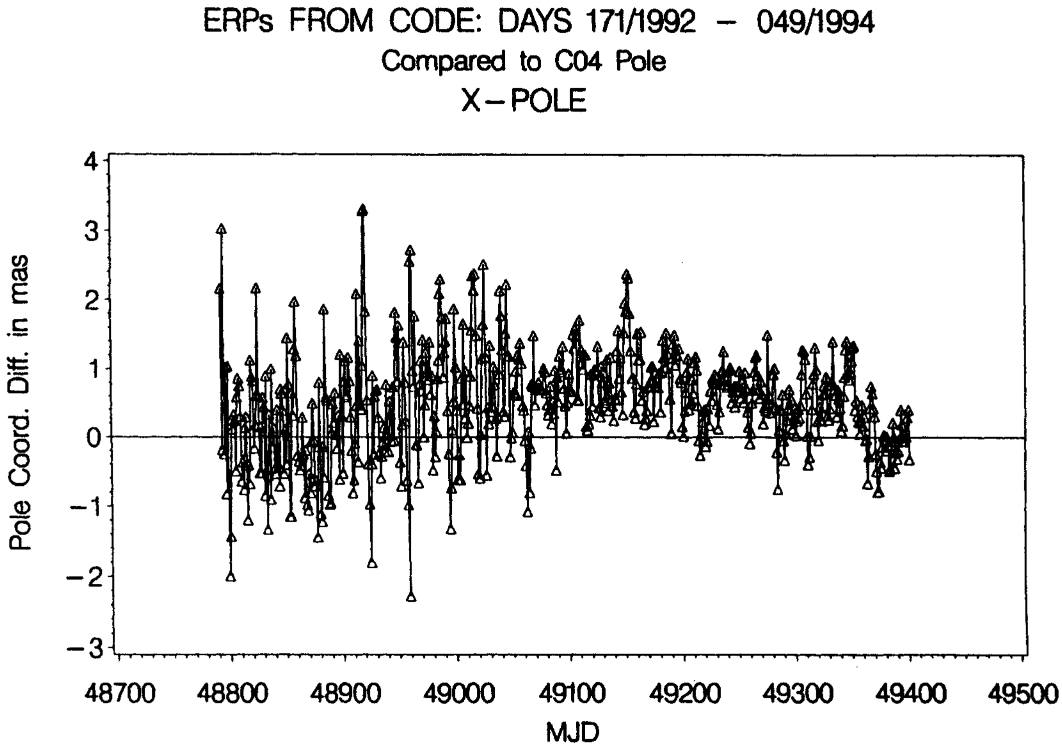

Figure 2a : Daily CODE Pole Estimates - C04 Pole Series (x-component)

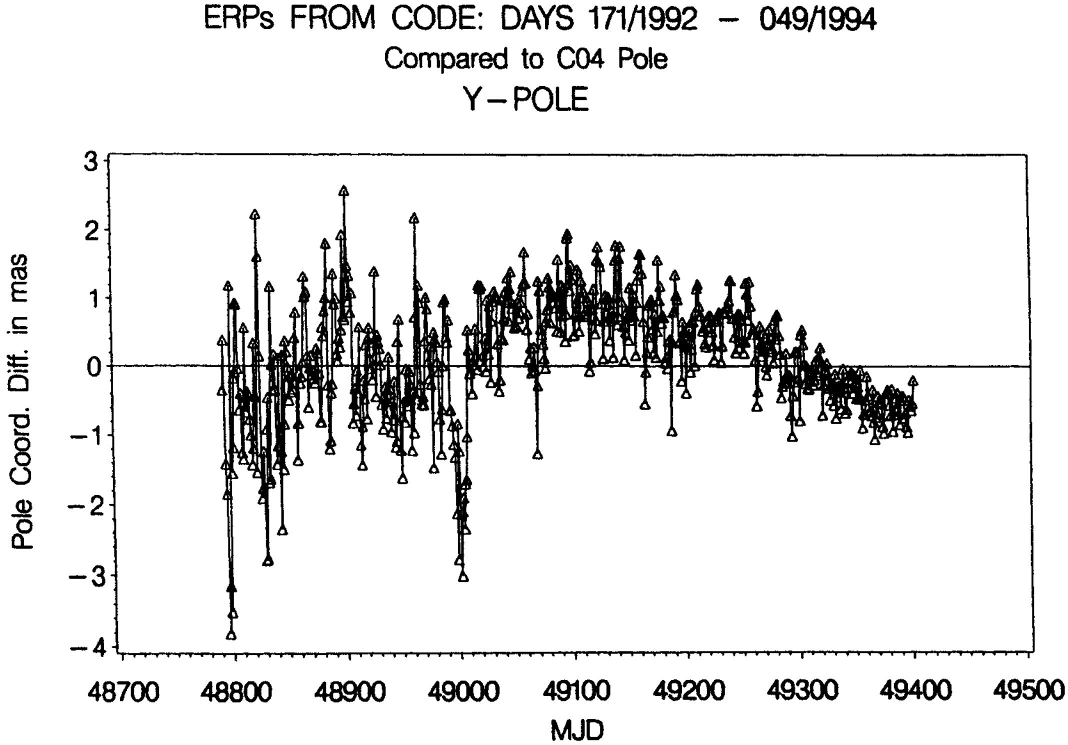

Figure 2b : Daily CODE Pole Estimates - C04 Pole Series (y-component)

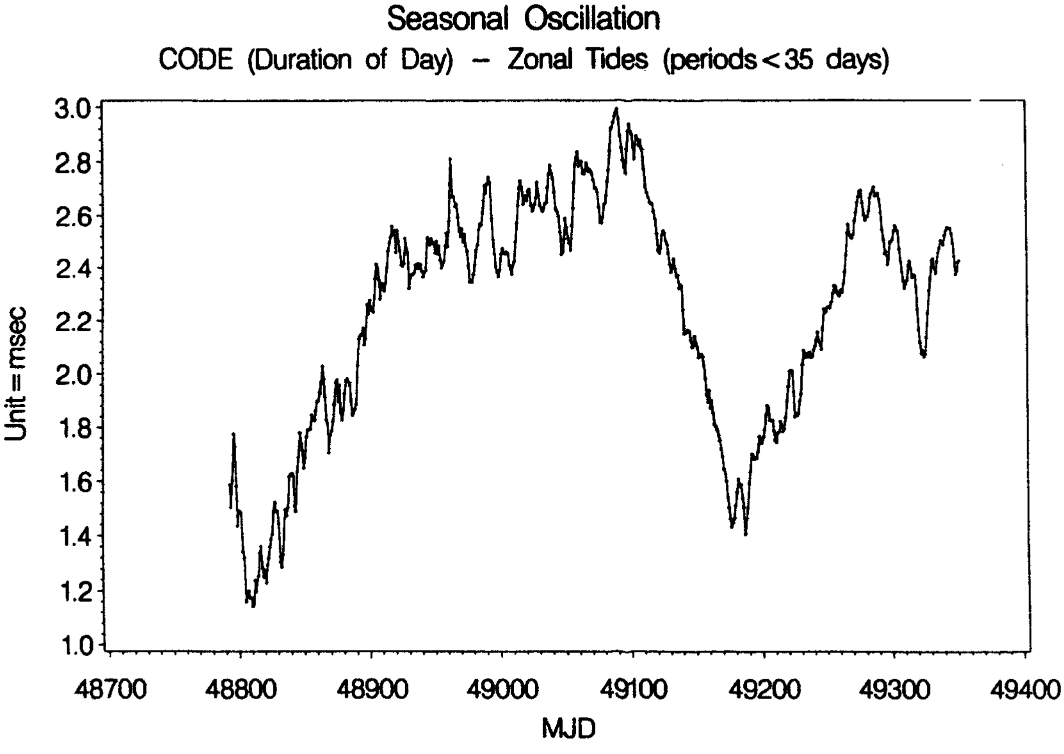

Figure 3a : Daily CODE Excess Day Length Values freed from zonal solid earth tides (periods shorter than 35 days)

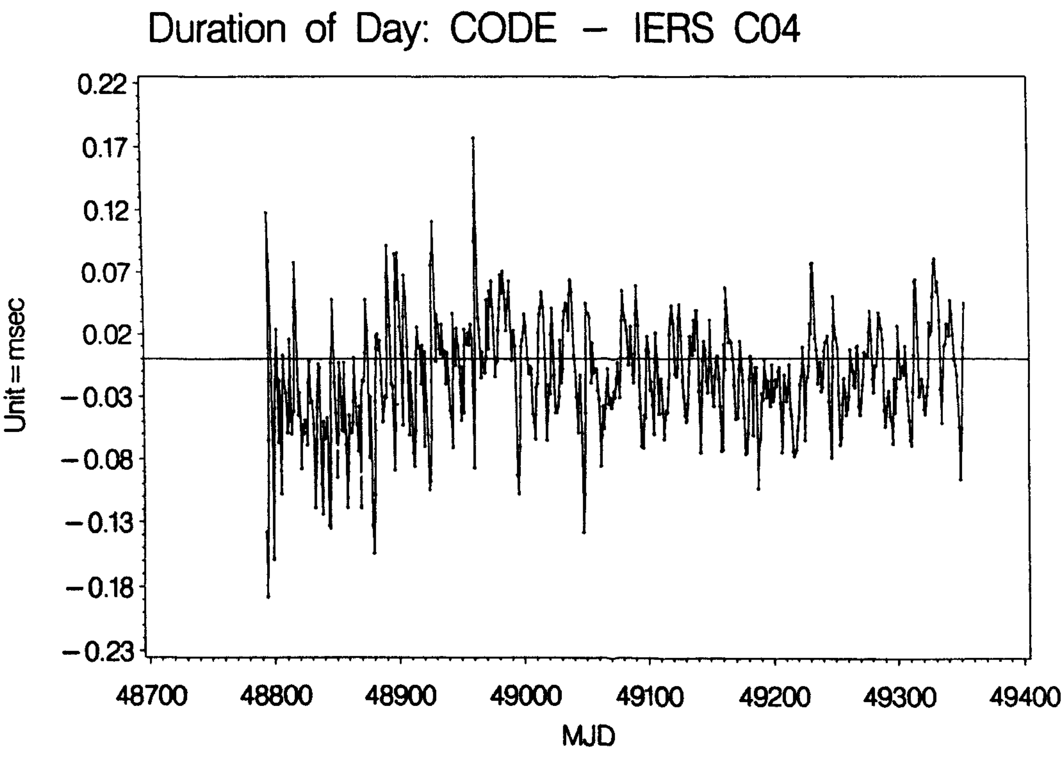

Figure 3b : CODE estimates - IERS C04 Series (Length of day)

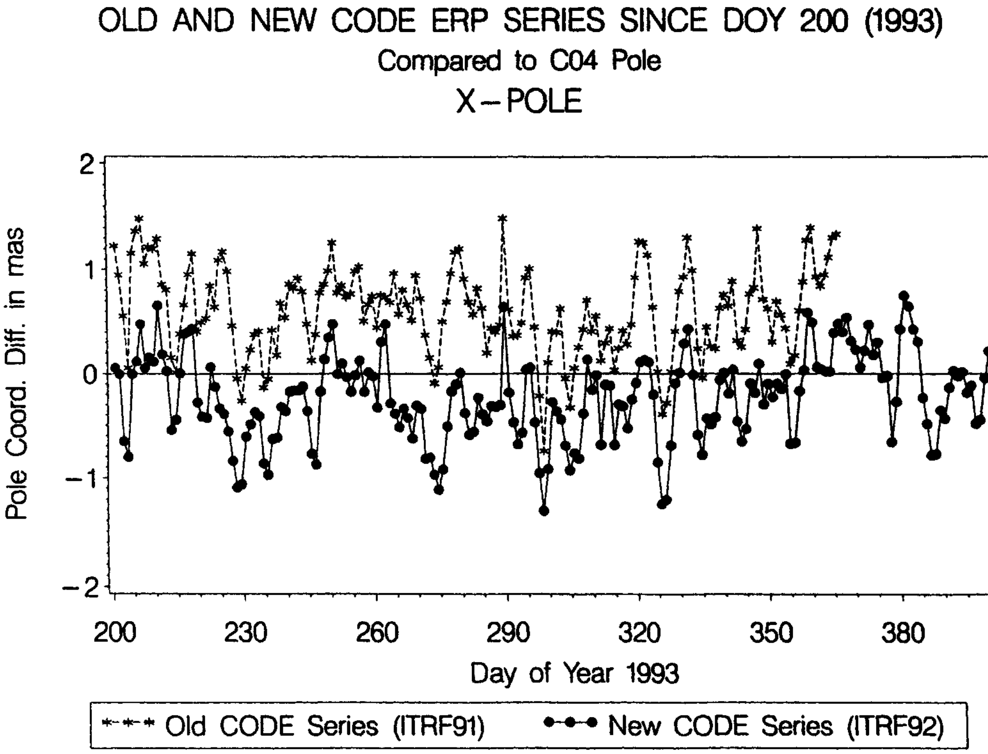

Figure 4a : CODE Estimates using the ITRF 91 of Table 1 - C04 Pole Series (*) and CODE Estimates using the ITRF 92 of Table 1 - C04 Pole Series (.) x-component

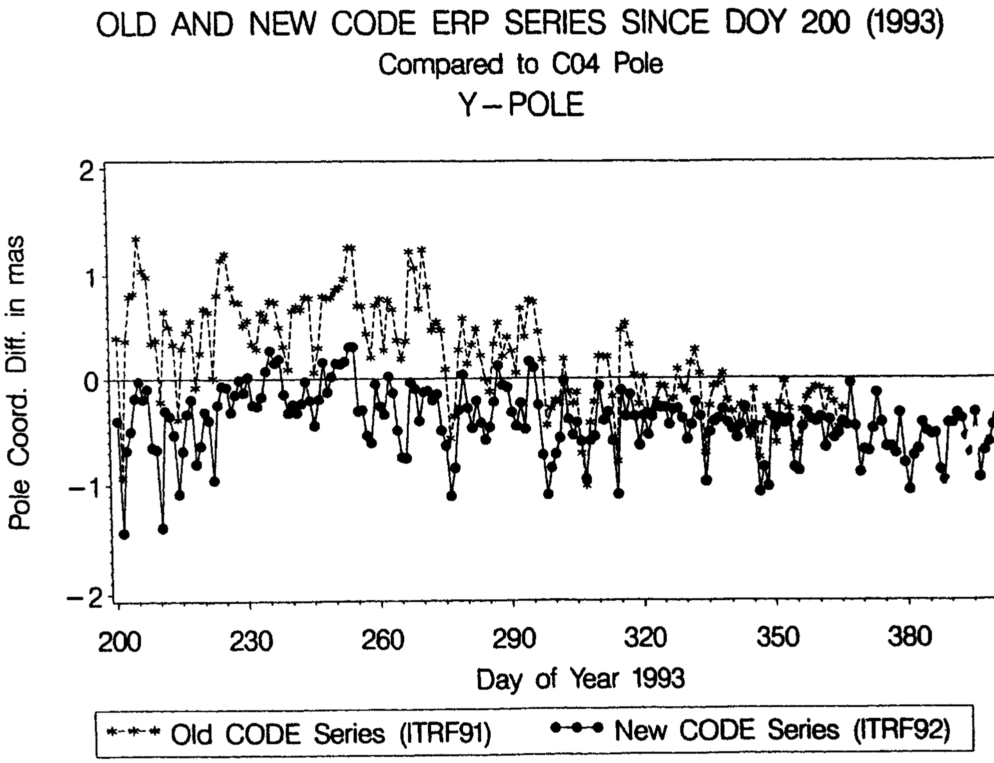

Figure 4b : CODE Estimates using the ITRF 91 of Table 1 - C04 Pole Series (*) and CODE Estimates using the ITRF 92 of Table 1 - C04 Pole Series (.) y-component

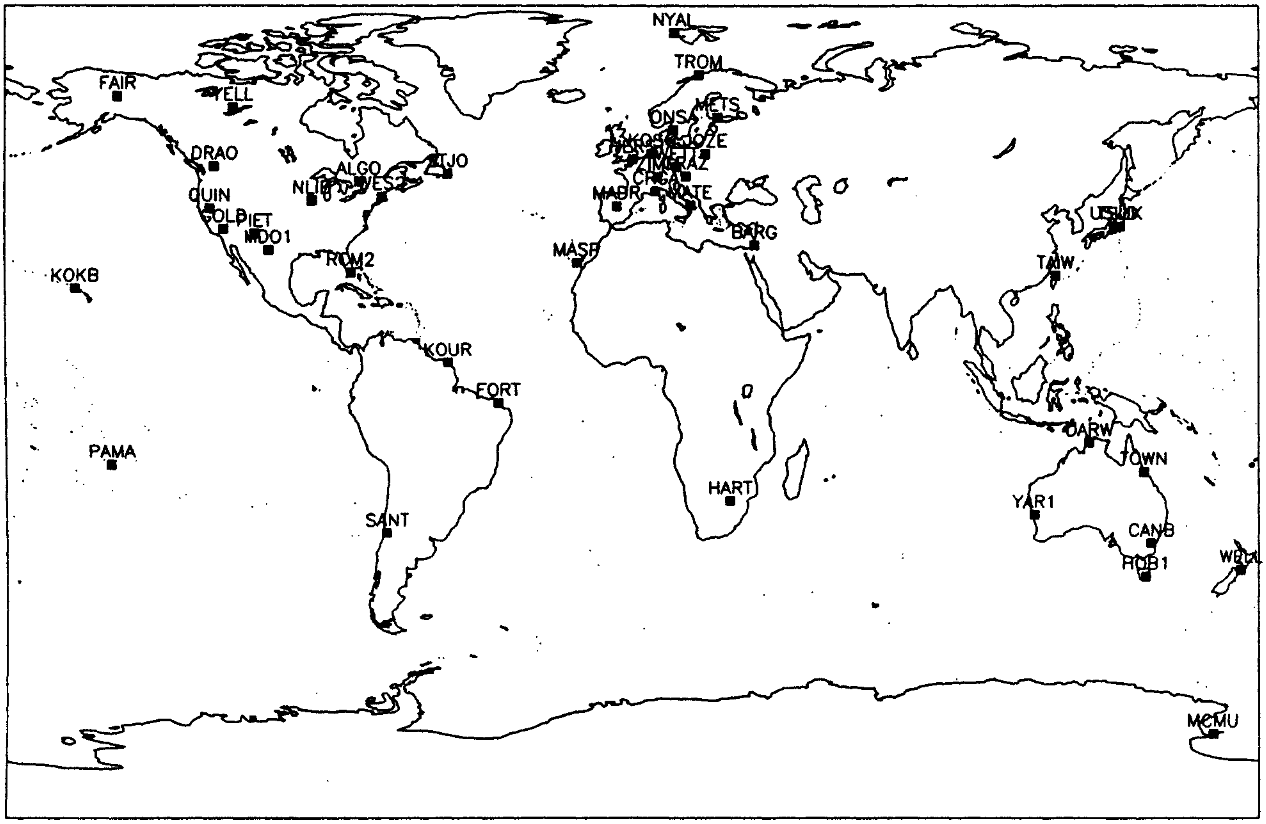

Figure 5 : IGS Core Stations used by the CODE Processing Center in 1993.

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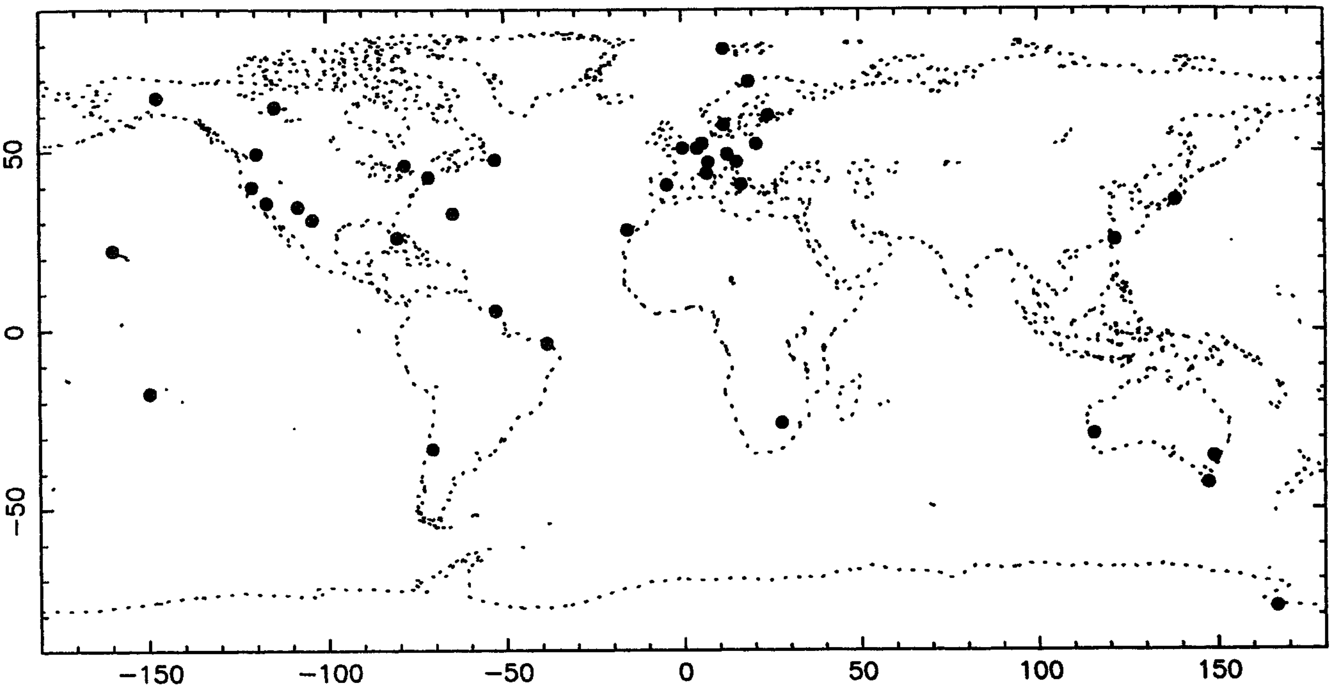
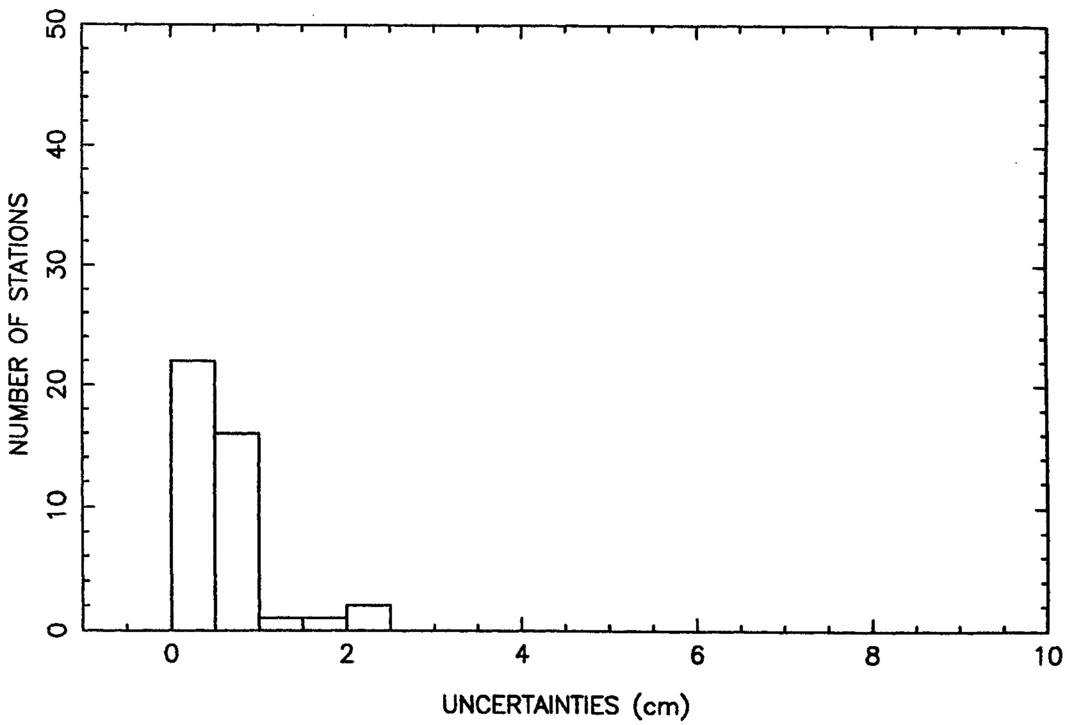
Summary description of the solutions CODE 94 P 01 and P 02

1 - Technique :	GPS
2 - Analysis Center :	CODE
3 - Solution identifier :	(a) A3 (94 P 01) (b) B3 (94 P 02)
4 - Software used :	Bernese GPS Sogftware, Version 3.5+
5 - Relativity Scale :	Local Earth
6 - Permanent tidal correction on station :	according to IERS standards
7 - Tectonic plate model :	ITRF 92 velocity model
8 - Velocity of light (C) :	299792458 m/sec
9 - Geogravitational constant (GMo) :	398.6004415 10^{12} m^3/sec^2
10 - Reference epoch :	15 Aug 1993 for both solutions
11 - Adjusted parameters :	- 6 Keplerian osculating elements, direct radiation pressure, and y-bias for each satellite and each 3-days arc, - pseudo-stochastic impulse changes (twice per day) for eclipsing satellites, - 4 tropospheric zenith delays per day and station, - ERPs as polynomials of degree 1 for each day (continuity at the day boundaries), - initial phase ambiguity parameters, - geocentric coordinates for each site, and, for solution (b) B3, velocity for each site.
12 - Definition of the origin :	no translation with respect to the official 13 IGS ITRF 92 stations
13 - Definition of the orientation :	no rotation with respect to the official 13 IGS ITRF 92 stations
14 - Constraints for time evolution :	(a) ITRF 92 Velocity Field (b) 1m/yr for north,east-components, 0.1mm/yr for up-component, for 28 stations. Wettzell fixed on ITRF 92 vel.



Distribution of the 39 sites of the terrestrial frame SSC(CODE) 94 P 01.



Distribution of the uncertainties (quadratic mean of δx, δy, δz) for the 42 stations of the terrestrial frame SSC (CODE) 94 P 01.

EOP(CODE) 94 P 02 From Jun 1992 to Dec 1993

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
1992	195	0.10	195	0.10	195	0.07
1993	364	0.06	364	0.06	364	0.06

EOP(CODE) 94 P 03 From Jul 1993 to Feb 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	166	0.05	166	0.05	166	0.06
1994	50	0.04	50	0.04	50	0.06

1993 GPS DATA PROCESSING AT THE EMR ANALYSIS CENTRE

EOP(EMR) 92 P 04
SSC(EMR) 94 P 02, 03, 04

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Since August 1992 the GSD's Master Active Control System (MACS) Centre has been reducing GPS data from six Canadian ACS stations augmented by up to 12 stations of the International Geodynamics GPS Service (IGS) global core station network. The GIPSY II/ OASIS GPS software system developed by the Jet Propulsion Laboratory has been adopted for daily processing. The GIPSY II processing has been highly automated using UNIX script to consolidate and integrate procedures into a single run. Twelve stations were constrained at the IGS coordinates (Table 2) and adopted constants, gravity and radiation pressure models conform to the IGS/IERS standards (Boucher *et al.*, 1992; McCarthy, 1992) The global ocean loading model due to Pagiatakis (1982) has been adopted. The submitted EMR EOP series is identical with our weekly submissions during 1993 and starts on January 1, 1993. All days are included even those with Anti Spoofing (AS) turned on.

The EMR processing is based on undifferenced phase and smoothed pseudorange data at 5 minutes sampling intervals using 15 degree elevation angle cut off. Both phase and pseudorange observations are considered uncorrelated and weighted according to sigmas computed from the following exponential model:

$$\sigma(E) = \sigma_0 + \sigma_1 e^{-E/E_0}$$

where E is the elevation angle in degrees and the constants are: E_0=20, σ_0=4 mm, σ_1=15 mm for phase measurements at all stations; σ_0=180 and 780 mm for pseudoranges at most stations. Some stations (e.g. PAMA, STJO, YELL) have higher pseudorange noise due to multipath and are being weighted accordingly. We have also enhanced the GIPSY II software to allow different weighting of satellites, data segment deletion and corrections of biases. This proved to be useful for data reduction when AS satellites can be down weighted, deleted or bias corrected. For AS data the pseudorange observations were down weighted by assigning very large sigmas (100 m).

We have adopted 24h arcs without any data 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 making the estimation process self contained. Broadcast orbits are used only when introducing a new satellite. Using the preceding arc solution is not only more accurate than the broadcast orbit initialization, but it also offers a self check on daily solutions and a quick indication of orbit errors and/or problems relating to a particular satellite.

The differences between the state vector estimation for successive days are typically below 1 m and values larger than 1.5 m are usually reported in the weekly summary files. In most cases larger differences have been found for eclipsing satellites. This approach also facilitates another type of orbit modelling and estimation of DUT1. By assigning a priori orbit sigmas of 1m and 0.5 mm/s in fact approximates a random walk stochastic process with daily updates and sigmas of 1m/sqrt(day) and (0.5 mm/s)/sqrt(day). This is due to the fact that the other sigmas are much smaller, typically below 10 cm and 0.03 mm/s. As a consequence of the colinearity between DUT1 and R. A. of the ascending orbit nodes, the estimated DUT1 contains both the DUT1 changes as well as the orbit node errors common to all satellites with sigmas and correlation characteristic of a random walk process, i.e. the covariance between day i and i+1 is var(i,i+1)= var(i,i).

The variance var(i,i) increases approximately with the sqrt(i), where i is the number of days since the DUT1 initialization. DUT1 is initialized the first non AS day of the GPS week using the most current USNO/IERS Bull. A values. The summary of estimated parameters, their a priori values and sigmas are listed in the Table 1.

Table 1 : Summary of estimated parameters, a priori values and sigmas

Parameters	type	a priori values	a priori sigmas
StationX,Y,Z	constant	IGS/ITRF91 (1992.5)	50m (fixed .002-.02m)
Pole x,y	"	IERS/USNO Bull. A	3m
DUT1	"	" "	3m ; fixed/reset every week
Trop. Z. dely	"	2.0m	.2m
Satell. states	"	prev. day solution	1km, .005m/s or 1m, .0005m/s
Sol. rad. Gx,Gz	"	1.0	.1 (10%)
Sol. rad. Gy	"	0	1.0 10E-9 m/s^2
Init. phase amb.	"	0	300000km
Trop. bias	random w.	0	.01m/sqrt(1h)
Station clock	w. noise	0	1s (ALGO H-Maser fixed)
Satell. Clock	"	0	0.001/.0001s for Block I/II

The orientation and to a large extend the scale of the EMR orbit/EOP solutions are nominally those of ITRF91 (epoch 1992.5) as realized through the set of up to 12 stations constrained at the ITRF91 coordinates which are primarily based on VLBI solutions (see the list of constrained stations in the summary description below). Also the DUT1 which is initialized once a week, usually on Sunday or the first non AS day of the week using the most current IERS/NOES Bull.A predictions is derived from VLBI DUT1 solutions.

The reported EOP sigmas are the formal sigmas as estimated by the adjustment. As experienced from the repeatability of position solutions the formal sigma may be too optimistic, and need to be multiplied by a factor of 2 or 3.

References

Boucher, C., Altamimi, Z., Dufour, J.P., and Fagard, H., 1992: The IERS terrestrial reference frame and its extensions by IGS and DORIS, presented at NASA DOSE meeting, GSFC Greenbelt, Md, October.

McCarthy, D.D. (ed), 1992: *IERS Technical Note No. 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.

Summary of solutions SSC (EMR) 94 P 02, 03 and 04

1 - Technique:	GPS
2 - Analysis centre :	Geodetic Survey Division (GSD), SMRSS , EMR
3 - Solution identifier:	1993 EMR Annual submission
4 - Software used:	GIPSY/OASIS II (UNIX)
5 - Relativity scale :	LE
6 - Permanent Tide corr:	none
7 - Tectonic plate mod.:	none, 3 epochs
8 - velocity of light:	299792458 m/s
9 - GM: gravity model:	389600.4414 km^3/s^5 GEMT3(8,8) +C21+S21
10 -reference epoch:	1993.21, 1993.5, 1993.83
11 - Adjusted parameters:	- undifferenced phase and smoothed pseudorange data > 15 degrees @ 5 min; - single day (24h) arc with 6 IC and 3 rad. parameters per satellite (up to 26sat.); - trop. zenith delay corr. parameter augmented with random walk stoch. process; - initial phase ambiguity parameters (1 for each satellite/station pass or initial phase); - station positions X,Y,Z, up to 18 stations. - x, y pole position, once a day (DUT1 fixed/solved; DUT1,x,y apriori sigma = 3m); - station clock biases once per each epoch/station (except for ALGO h. maser which provides the time reference) with sigma 1 s; - satellite clock biases once per each epoch/satellite with 1ms or.1ms sigma.
12 -origin:	Nominally ITRF91
13 -orientation:	" " "
14 -Constraint for t. evolution:	none

Summary of solution EOP (EMR) 92 P 04

1 - Analysis centre: Geodetic Survey Division (GSD), SMRSS , EMR

2 - Solution identifier: Annual submission

3 - Software used : GIPSY/OASIS II (UNIX)

4 - Definition of Terrestrial frame:

origin:	Nominally ITRF91
orientation:	" "
reference epoch:	1992.5
velocity of light :	299792458 m/s
GM:	398600.4414 km^3/s^5
gravity model:	GEMT3(8,8) +C21+S21
permanent tide corr:	None
ocean loading :	Pagiatakis, global model

5 - Adjusted parameters:

undifferenced phase and smoothed pseudorange data > 15 degrees @ 5 min. single day (24h) arc with 6 IC and 3 rad. parameters per satellite (20sat.)

trop. zenith delay corr. parameter augmented with random walk stoch. process

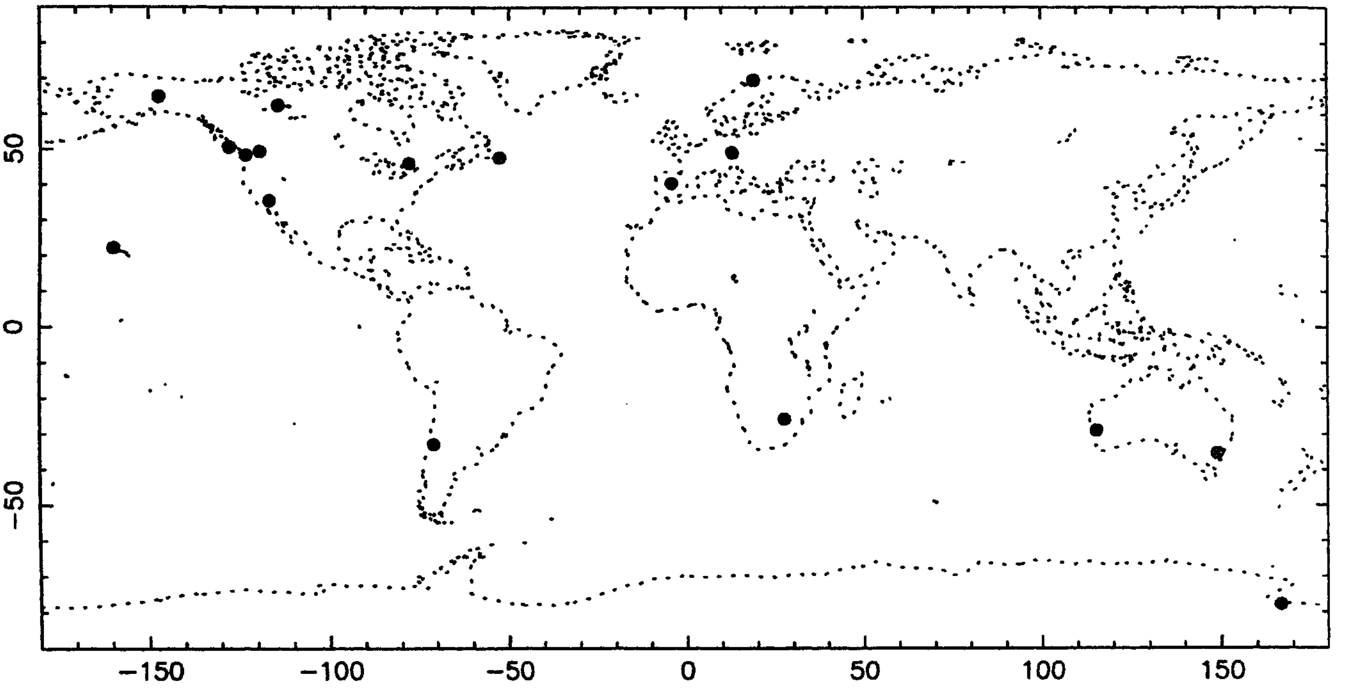
initial phase ambiguity parameters (1 for each satellite/station pass or initial phase)

station positions X,Y,Z, up to 19 stations, ALGO, FAIR, GOLD, HART, SANT, TROM, WETT, YELL, MADR, MCMU, TIDB and YAR1 constrained.

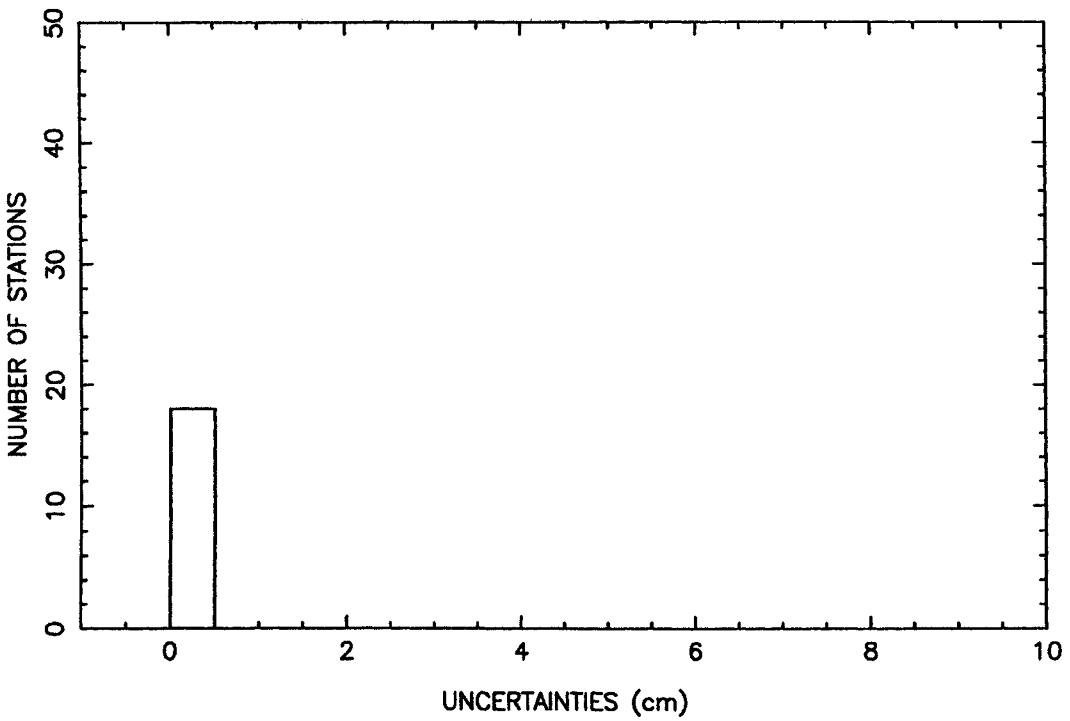
x, y pole position once a day (DUT1 fixed/solved; DUT1,x,y apriori sigma=3m)

station clock biases once per each epoch/station (except for ALGO h. maser which provides the time reference) with sigma 1 s

satellite clock biases once per each epoch/satellite with 1ms or .1ms sigma



Distribution of the 17 sites of the terrestrial frame SSC(EMR) 94 P 02.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 18 stations of the terrestrial frame SSC(EMR) 94 P 02.

EOP(EMR) 92 P 04 From Oct 1992 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
1992	64	0.22	64	0.18	41	2.40
1993	365	0.21	365	0.17	265	2.20

ANNUAL REPORT FROM THE ESOC ANALYSIS CENTRE FOR 1993

EOP(ESOC) 92 P 02
SSC(ESOC) 94 P 01

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The ESOC contribution to the IERS for 1993 consists of a daily Earth Orientation Parameter solution, EOP(ESOC) 92 P 02, and a GPS station coordinate solution, SSC(ESOC) 94 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 21 two day arcs of GPS observation equations from 1993.

1. DESCRIPTION OF THE EOP(ESOC) 92 P 02 SERIES FOR 1993

1.1 Daily IGS processing at ESOC

GPS data from every day of 1993 have been used to obtain orbits, Earth Orientation Parameters, and as of November 28, satellite clock biases. The incoming GPS data from about 24 stations is evaluated on a daily basis and EOPs are determined for 24 hour intervals. The initial values are taken from IERS Bulletin A predictions. RINEX observation files are the input of the GPSOBS program, that checks for cycle slips, obtains initial estimates for clock biases, obtains independent double differenced phase observations and prepares the inputs for BAHN, our orbit and geodetic parameter estimation program. BAHN makes an adjustment estimating orbits, positions of some stations, tropospheric parameters, measurement biases, receiver clock biases and EOPs. If precise satellite clock biases are needed GPSOBS can also obtain them in post processing using code and carrier phase observations and fixing the values of earth fixed orbits, tropospheric parameters and position of stations to those obtained by BAHN. Daily solutions are grouped in GPS week batches and sent to the IERS to be used in the IERS EOP combination.

1.2 Models and constants used

- Terrestrial reference frame

It is defined by fixing a set of 11 to 13 ground stations to the values given by the IERS and by using a velocity field that was NNR-Nuvel1 up to March 13 1993 and ITRF92 from March 14 1993. The geocentre is defined through the gravity model (C10 = C11 = S11 = 0).

- Integration of the equations of motion

This is done in the standard J2000.0 celestial frame. The relativity scale is that of the local Earth.

- Transformation between terrestrial and celestial reference frames

The IERS standards are used to transform from celestial frame to the terrestrial reference frame, including celestial pole offset from IERS Bulletin A. EOP's are modelled as constant during every UTC day, with a constant pole position (xp, yp). UT1 was modelled with a constant UT1 rate up to October 30 1993, and from October 31 1993 a constant value of UT1 regularized (UT1R) rate was used, so the UT1 rate could have the variations during the day predicted by the difference between UT1 and UT1R. The parameter that is provided to the IERS is the Length Of the Day (LOD), and as of October 31 LODR. UT1 series can be reconstructed from LOD or LODR values when a initial value is given.

- Basic constants

Velocity of light:	c	= 299792.458 km/s
Earth gravitational constant:	GM	= 398600.4415 km^3/s^2
Mean equatorial Earth radius:	Ae	= 6378.137 km
Solid Earth tidal Love number:	h_2	= 0.6090
Solid Earth tidal Shida number:	l_2	= 0.0852

- GPS data handling

The basic observable for BAHN is double-difference of carrier phases, using the ionospheric free combination. The elevation cutoff angle is 20 degrees and IGS evaluation was done using 24 hour arcs up to April 3 1993 and 48 hour arcs from April 4 1993. The 48 hours include the central day and two periods of 12 hours before and after.

- Satellite force model

Geopotential, GEM-T3 (n=8, m=8 plus C21 = $-0.17\ 10^{-9}$ and S21 = $1.19\ 10^{-9}$)
Solar third body attraction
Lunar third body attraction
Solid tides, k2 = 0.300, phi = 0, Wahr frequency dependent corrections
Ocean tides, Schwiderski; n=6, m=2, 11 tidal constituents
Non-Gravitational: Solar pressure + radiation emission models from Fliegel, T10 for Block I satellites and T20 for Block II/ IIA satellites. A constant scale factor and a Y-bias are estimated for every arc.

- Corrections to the measurements

Satellite centre of mass correction: For Block I satellites, in body fixed, dx = 0.210 m, dz = 0.854 m. For Block II satellites, dx = 0.279 m, dz = 1.026 m.
Ionospheric correction: Through the use of L3 ionospheric free combination.
Tropospheric correction: Zenith delay estimated linearly in 3 hour intervals up to April 3 1993. From April 4 1994 zenith delay and shape factor estimated linearly in 6 hour intervals.
Receiver L3 antenna phase centre correction: A vertical offset from the antenna reference point of 0.050 m for Rogue/MiniRogue antennas and of 0.082 m for TurboRogue antennas.

Antenna heights and local ties: from IGS Mail 90 up to March 13 1993, from IGS Mail 160 from March 14 1993 up to December 26 1993, from the localtie.tab file maintained at the IGS Central Bureau from December 27 1993.

1.3 Results

The EOP series obtained by ESOC for 1993 have been weekly sent to the IERS.

Table 1: Initial values and constraints used. When two values of constraint appear, the first was used up to April 3, 1993 and the second from April 4, 1993.

Parameter	Initial value	A priori constraint
Satellite position at epoch	From previous day orbit	100 m
Satellite velocity at epoch	From previous day orbit	0.1 m/s , 1 m/s
ROCK4 scaling factor	1.0 (0.88 for PRN# 23)	0.05 , 0.1
Y-bias	0.0	2e-6 N , 1e-6 N
xp, yp	IERS Bulletin A	5 mas , 100 mas
LOD / LODR	IERS Bulletin A	0.5 ms/d , 6 ms/d
Station position	ITRF91 / ITRF92	0.2 m , 50 m
Total tropos. zenith delay	2.1 m	0.2 m
Ambiguities	0.0	3e-8 m

Table 2: History of changes for 1993

Date	MJD	Description of change
Mar. 7	49053	New station coordinates SSC(ESOC) P 01 used. Before the station coordinate set from IGS Mail 90 was used.
Mar. 14	49060	New station coordinates and velocities from the ITRF91 used. Before the velocities were derived from the NNR-Nuvel1 model.
Apr. 4	49081	48 hour arc used for orbits adjustment. New a priori constraints.
Sep. 12	49242	Receiver clock biases estimated. Before these biases were supposed to be zero. Intial values obtained from GPSOBS and used with an a priori constraint of 1 microsecond.
Oct. 31	49291	LODR estimated instead of LOD. Improved UT1 modelling as a consequence. More passes and observations used. Implemented the capability of excluding manoeuvering satellites from affecting the EOP estimate.
Dec. 26	49347	New station coordinates and velocities from the ITRF92.

2.DESCRIPTION OF THE GPS STATION COORDINATE SOLUTION SSC(ESOC) 94 P 01

2.1 Input data

- Sites included

The stations that were included in the analysis were those stations that the ESOC/IGS Analysis Centre was using in January of 1994 for the daily IGS processing. They included all the 13 stations that are kept fixed for daily IGS processing, 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. The stations used are listed in the Table 3.

Table 3: Stations used in the station coordinate solution

Domes number	Name	IGS code	Operator	Receiver type	Tectonic plate
10302M003	Tromso	TROM	SK	Rogue	Eurasia
10403M002	Kiruna	KIRU	ESOC	TurboRogue	Eurasia
12734M008	Matera	MATE	ASI/Telespazio	Rogue	Eurasia
13407S012	Madrid	MADR	JPL/DSN	Rogue	Eurasia
13504M003	Kootwijk	KOSG	DUT	Rogue	Eurasia
14201S020	Wettzell	WETT	IfAG	Rogue	Eurasia
21729S007	Usuda	USUD	JPL	Rogue/TurboR.	Eurasia
23601M001	Taipei	TAIW	IES/AS	Rogue	Eurasia
30302M002	Hartebeesthoek	HART	SAC/CNES	Rogue	Africa
31303M001	Maspalomas	MASP	ESOC	MiniRogue	Africa
40104M002	Algonquin	ALGO	NRCan	Rogue	North America
40127M003	Yellowknife	YELL	NRCan	MiniRogue	North America
40405S031	Goldstone	GOLD	JPL/DSN	Rogue	North America
40408M001	Fairbanks	FAIR	JPL	Rogue	North America
40424M004	Kokee Park	KOKB	JPL	Rogue	Pacific
40499M002	Richmond	RCM2	NOAA	Rogue	North America
40499S018	Richmond	RCM5	NOAA	TurboRogue	North America
41602M001	Fortaleza	FORT	INPE/NOAA	TurboRogue	South America
41705M003	Santiago	SANT	JPL	Rogue	South America
50103M108	Tidbinbilla	TIDB	JPL/DSN	Rogue	Australia
50107M004	Yarragadee	YAR1	JPL	Rogue	Australia
50133M001	Perth	PERT	ESOC	TurboRogue	Australia
66001M001	McMurdo	MCMU	JPL	Rogue	Antarctica
92201M003	Pamatai	PAMA	CNES	Rogue	Pacific
97301M210	Kourou	KOUR	ESOC	MiniRogue	South America

- Arcs included

The periods of data used were:

Seven two day arcs from January 17th 1993 to January 30th 1993, using 21 GPS satellites.

Seven two day arcs from July 4th 1993 to July 17th 1993, using 23 GPS satellites.

Seven two day arcs from December 19th 1993 to January 1st 1994, using 26 GPS satellites.

Neither anti-spoofing was activated nor satellites were manoeuvered during these three periods. Not all the stations were available during these six weeks. The actual stations used for every arc are listed in Table 4. Kokee Park (KOKB) was excluded from the December Analysis because it did not produce good data for some days.

Table 4: Data spans used

IGS	January 1993							July 1993							December 1993						
code	17	19	21	23	25	27	29	04	06	08	10	12	14	16	19	21	23	25	27	29	31
TROM	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
KIRU											**	**	**	**	**	**	**	**	**	**	**
MATE	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
MADR	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
KOSG	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
WETT	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**					**
USUD	**	**	**	**	**	**	**						**	**	**	**	**	**	**	**	**
TAIW	**	**		**	**	**	**	**	**	**	**	**	**		**	**	**	**	**	**	**
HART	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
MASP	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
ALGO	**	**	**	**	**	**	**		**	**	**	**	**	**	**	**	**	**	**	**	**
YELL	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
GOLD	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
FAIR	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
KOKB	**	**	**	**	**	**	**	**	**	**	**	**	**	**							
RCM2				**		**	**	**	**	**	**		**	**							
RCM5															**	**	**	**	**	**	**
FORT															**	**			**	**	**
SANT	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
TIDB	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
YAR1			**	**	**	**	**	**	**	**	**	**			**	**	**	**	**	**	**
PERT															**		**	**	**	**	**
MCMU					**		**	**		**	**	**		**							
PAMA	**	**	**	**	**	**	**								**	**	**	**	**	**	**
KOUR	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**

- Initial station coordinates

Initial station coordinates were obtained from the ITRF92 station coordinate solution, as listed in IGS Mails 421 and 430. Station positions were calculated at the different epochs using the velocities of the ITRF92. To obtain the velocities of those stations not included in the ITRF92 (KIRU, FORT, PERT) and also for TROM and YELL the NNR-Nuvel-1 velocity field was used. Coordinates for stations not listed in these mails (KIRU, RCM5, FORT, PERT) were obtained from the average estimates from one week of IGS processing. Local ties and antenna heights were obtained from the file localtie.tab maintained by the IGS Central Bureau.

- Observation equations

The parameters that were estimated in the generation of the observation equations were:

Satellite position and velocity for the start of each arc and a scale radiation pressure and a y-bias for each arc.
Tropospheric biases, modelled linearly in 6 hour intervals.
Measurement biases for the double difference phase observations.
Receiver clock biases and drifts, as needed.

Observation equations were also obtained for other parameters, fixing for each arc their value to some initial value:

Earth rotation parameters, with initial values from the IERS Bulletin B.
Station coordinates.

- Normal equations

Normal equations were obtained from the observation equations eliminating those parameters that were not of interest for subsequent processing. The only parameters kept were station coordinates and earth orientation parameters.

2.2 Data analysis

- Free network solutions

First station coordinate solutions were obtained separately for every arc in order to verify the quality of the data from each arc. These solutions were then compared with three two week solutions for January, July and December. Only observability problems were found for one or two stations for a couple of arcs, but they were solved by combining these arcs with other with better observability for those stations. Then a global solution was obtained and compared with the two week solutions to obtain an estimate of the repeatability of the solutions. All these solutions were obtained fixing the ERP values to the initial IERS Bulletin B values and without using any other additional constraint, so they can be considered "free network" solutions. Table 5 compares the two week solutions with each other and with the global free network solution.

Table 5. Discrepancies after 7 parameter transformation.

First set	Second set	rms of East discrepancies (cm)	rms of North discrepancies (cm)	rms of Height discrepancies (cm)
Jan. solution	Jul. solution	1.8	1.2	3.7
Jul. solution	Dec. solution	3.3	1.5	3.7
Jan. solution	Dec. solution	3.9	1.3	3.1
Global solution	Jan. solution	1.6	0.7	1.9
Global solution	Jul. solution	1.4	1.1	2.5
Global solution	Dec. solution	2.6	0.7	1.7

Typical accuracy based in repeatability can be estimated to about 2.2 cm east, 1.0 cm north and 2.5 cm vertical for the two week solutions and about 1.3 cm east, 0.6 cm north and 1.5 cm vertical for the global solution. When the global free network solution is compared with the initial values (mostly ITRF92), the results are those shown in Table 6.

Table 6. Comparison of the global free network solution with the initial values after a seven parameter transformation to obtain the new coordinates in the same reference

	centre offset			rotations				residual rms		
	x	y	z	x	y	z	scale	East	Nor.	Hei.
reference set	(cm)	(cm)	(cm)	(mas)	(mas)	(mas)	(ppm)	(cm)	(cm)	(cm)
All stations	-0.25	-7.15	17.88	-1.55	-0.61	-10.10	0.000	1.2	1.1	3.1
ITRF92	-0.33	-6.90	17.59	-1.67	-0.68	-10.17	0.001	1.2	0.9	3.3
IGS fiducial	0.07	-6.88	17.29	-1.63	-0.57	-9.95	0.000	0.9	0.6	3.0

The comparison shows agreement with the initial coordinates to about 1 cm horizontal and 3 cm vertical. All the initial coordinates, those obtained from the IERS as well as those obtained from one week of IGS results, seem to be equally accurate. There is no significant difference between the accuracy of the 13 stations that are used as fiducial sites for the daily solution and the other sites.

- Discussion on constraints

As we see in Table 6 a free network solution can be shifted and rotated with respect to the reference solution. The biggest shift is always for the GPS solutions that we have obtained a z axis displacement and the biggest rotation is, as expected for a satellite based solution, a z rotation. We would like to have our solution in the same reference as the original ITRF92 set without having to post-process the coordinate set. This can be done using constraints for the station coordinates that stabilize our system without changing the relative position of the stations. Another additional problem is that free network solutions do not provide a credible estimate of the accuracy of the coordinates. Calculated absolute accuracies are as big as 7 meters for the longitude of some stations in the global free network solution. Two kinds of constraints will be used. The first will be a so called seven parameter constraint, that constrains the displacements of a group of stations so the average shift, rotation or scale are kept unchanged. The second, needed to obtain estimates of the accuracy, is a loose a priori constraint for every component of a group of stations so that the system is stabilized.

- Solution SSC(ESOC) 94 P 01

For this solution the following constraints were applied:

Earth rotation parameters were fixed to the IERS Bulletin B values.

The origin and z rotation of the system defined by the set of 13 stations that are fixed for the daily solution were constrained to be zero. X and y rotation were not fixed because it would conflict with fixing the centre of the system and the position of the pole. The scale factor is well determined and does not need to be fixed.

All the station coordinates were loosely constrained to the a priori values with 1 m for every component.

2.3 Results

- Effect of constraints

The first thing that has to be analyzed is how the constraints that have been applied have affected the solution. For that we compare in Table 7 the constrained solution with the free network solution, with the initial coordinates and with the initial coordinates of the set of fiducial stations

Table 7. Comparison of the SSC(ESOC) 94 P 01 with reference sets after a seven parameter transformation to obtain the new coordinates in the same reference

	centre offset			rotations				residual rms		
	x	y	z	x	y	z	scale	East	Nor.	Hei.
reference set	(cm)	(cm)	(cm)	(mas)	(mas)	(mas)	(ppm)	(cm)	(cm)	(cm)
Free network	-0.02	6.49	-17.23	-0.17	-0.15	9.74	0.000	0.5	0.3	1.0
Initial set	-0.27	-0.66	0.65	-1.72	-0.76	-0.36	0.001	1.5	1.1	2.8
IGS fiducial	-0.02	0.02	0.01	-1.80	-0.75	-0.21	0.001	1.2	0.8	2.9

The comparison with the free network set shows that the constraints have effects that are smaller than the repeatability of the solution, so we can say that the adjustment is not over-constrained. The x and y rotations are basically the same as in the free network solution, because they are fixed by fixing the pole position to the IERS Bulletin B values. The discrepancy with the ITRF92 in these two rotations, that we can see both in the comparison with the initial set and the fiducial set, can be explained using the predicted biases and slopes given in the 1992 IERS Annual Report (p. II-17). The offset at 1993.5 should be 0.34 0.5 for xp and 1.53 0.5 for yp. These offsets make the IERS EOP series consistent with the IERS terrestrial reference frame. The comparison with the IGS fiducial set shows that the origin and z rotation constraint has worked as expected, fixing the origin of the system and the rotation about the z axis. In addition, the sigmas of the solution have now values that are closer to those expected by the repeatability, so the 1 m constraint has produced the desired effect without overconstraining the system.

- Accuracy of the solution

Agreement with the set of initial coordinates, basically ITRF92, is in the same order of magnitude as the accuracy of the solution based on repeatability. In Table 8 three measurements of the accuracy of the solution are compared.

Table 8. Accuracy estimates

Measurement of accuracy	East estimate (cm)	North estimate (cm)	Height estimate (cm)
Repeatability	1.3	0.6	1.5
Comparison with ITRF92	1.5	1.1	2.8
Average formal uncertainties	3.7	1.5	3.2

The formal uncertainties seem to be pessimistic, specially for the East accuracy.

- Velocity field

To check whether the velocity field may need improvement for some sites, we have compared the discrepancies of the two week solutions with respect to the global solution, after a seven parameter transformation, with the formal uncertainties for each site. If the discrepancies were higher than the formal uncertainties we could suspect that the velocities might be not well determined, but all the discrepancies are well within 3 sigma of the estimates, so an improved velocity field solution does not seem possible with this data set.

Summary description of the solution SSC(ESOC) 94 P 01

1 - Technique:	GPS
2 - Analysis Centre:	ESA / European Space Operations Centre (ESOC)
3 - Solution identifier:	SSC(ESOC) 94 P 01
4 - Software used:	GPSOBS/BAHN-V5/MULTIARC
5 - Relativity Scale:	Local Earth
6 - Permanent tide correction on station:	To be added to listed coordinates
7 - Tectonic plate model:	ITRF92 + NNR-Nuvel1
8 - Velocity of light (c):	299792.458 km/s
9 - Geogravitational constant (GMo):	398600.4415 km^3/s^2
10 - Reference epoch:	1994.0

11 - Adjusted parameters:

On a two day basis:

Satellite parameters per spacecraft:
- one orbital state at start epoch.
- one scaling factor for radiation pressure ROCK4 T10 or T20 models.
- one Y-bias acceleration.

Station related parameters per ground station:
- every 6 hours an atmospheric zenith delay parameter and a shape parameter.
- clock biases and clock drifts as needed.
- double-differenced phase ambiguities as real-valued parameters.

For the whole campaign:

Station related parameters per ground station:
- ground station positions

Parameters to be kept fixed:

Satellite parameters per spacecraft:

- radiation pressure scaling factors Gx and Gz fixed to 1.0.

Station related parameters per ground station:

- site velocities from ITRF92 or NNR-Nuvel1 when the site is not listed in the ITRF92.

EOP values

- from the IERS Bulletin B.

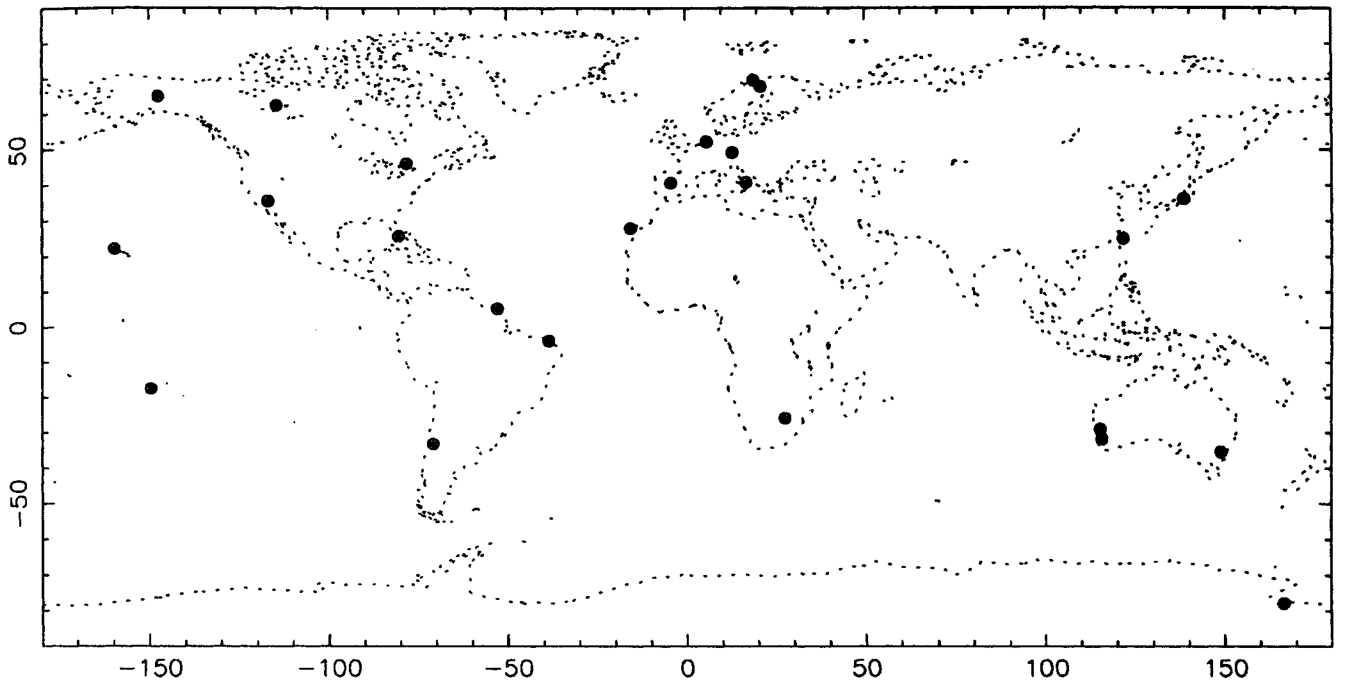
12 - Definition of the origin: Origin of a set of 13 fiducial stations constrained to be the same as that of the ITRF92. These stations are: Madrid, Kootwijk, Wettzell, Tromso, Hartebeesthoek, Yarragadee, Tidbinbilla, Kokee Park, Fairbanks, Goldstone, Yellowknife, Algonquin and Santiago.

13 - Definition of the orientation: the EOP's are fixed to IERS Bulletin B, the rotation about the z axis of the set of 13 fiducial stations constrained to be the same as that of the ITRF92.

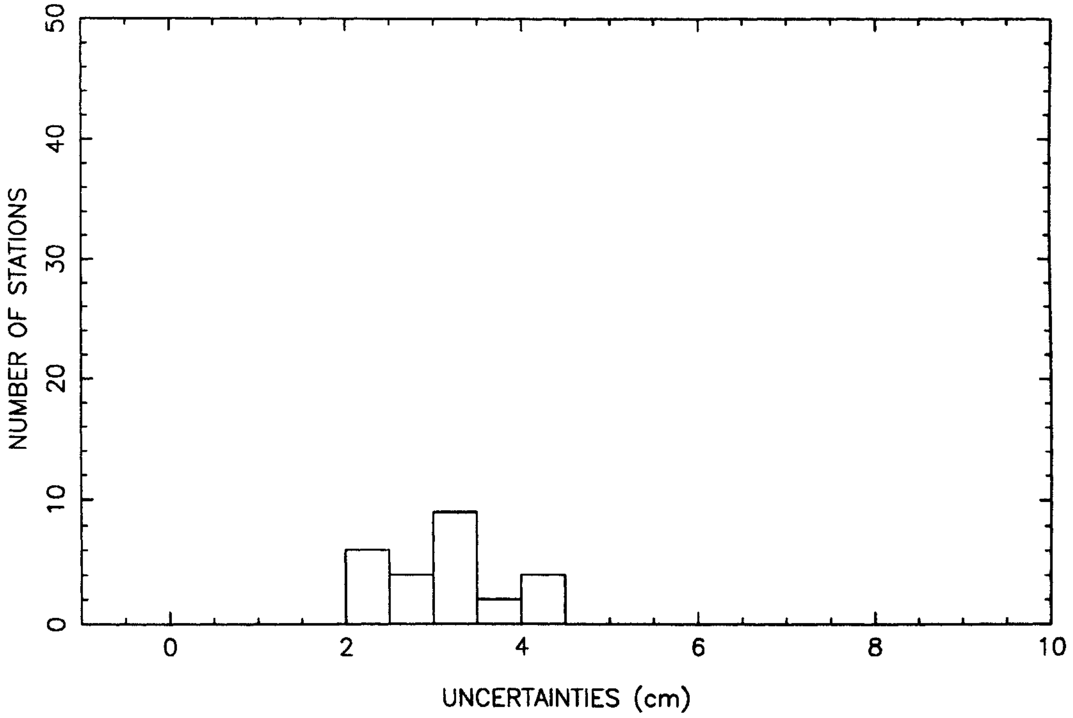
14 - Constraint for time evolution: ITRF92 and NNR-Nuvel1 plate motion model

15 - Deviations from the IERS standards:

- no relativistic corrections to propagation or/and acceleration.
- no station ocean loading.



Distribution of the 24 sites of the terrestrial frame SSC(ESOC) 94 P 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 25 stations of the terrestrial frame SSC(ESOC) 94 P 01.

Summary description of solution EOP(ESOC) 92 P 02

1 - Technique: GPS
2 - Analysis Centre: ESA / European Space Operations Centre (ESOC)

3 - Solution identifier: EOP(ESOC) 1993
4 - Software used: GPSOBS/BAHN-V5
5 - Relativity Scale: Local Earth
6 - Permanent tide correction on station: To be added to listed coordinates
7 - Tectonic plate model: ITRF92 + NNR-Nuvel1
8 - Velocity of light (c): 299792.458 km/s
9 - Geogravitational constant (GMo): 398600.4415 km^3/s^2
10 - Reference epoch: 1993.5
11 - Adjusted parameters:

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.
- ground station positions for stations that are not fixed

Earth Orientation Parameters (EOPs):
- one set of pole coordinates xp, yp and LODR per day.

Parameters to be kept fixed:

Satellite parameters per spacecraft:
- radiation pressure scaling factors Gx and Gz fixed to 1.0.

Station related parameters per ground station:
- site velocities from ITRF92 or NNR-Nuvel1 when the site is not listed in the ITRF92
- The coordinates of 13 fiducial stations are fixed to the ITRF92 values. These stations are: Madrid, Kootwijk, Wettzell, Tromso, Hartebeesthoek, Yarragadee, Tidbinbilla, Kokee Park, Fairbanks, Goldstone, Yellowknife, Algonquin and Santiago

12 - Definition of the origin: Geocentre through gravity model (C10 = C11 = S11 = 0).
13 - Definition of the orientation: By fixing the coordinates of 13 fiducial stations to the ITRF92 values.
14 - Constraint for time evolution: ITRF92 and NNR-Nuvel1 plate motion model
15 - Deviations from the IERS standards:
- no relativistic corrections to propagation or/and acceleration.
- no station ocean loading.

EOP(ESOC) 92 P 02 From Sep 1992 to Dec 1993

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	100	0.26	100	0.26	47	0.45
1993	359	0.15	359	0.16	359	0.21

EARTH ROTATION PARAMETERS AND STATION COORDINATES FROM GPS DATA

EOP(GFZ) 94 P 02, 03,
SSC(GFZ) 94 P 01

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A global Set of Station Coordinates (SSC(GFZ) 94 P 02) and Earth Rotation Parameters (ERP(GFZ) 94 P 02) have been computed by GFZ from the 1993 global GPS data set and with the GPS analysis Software package EPOS.P.V2. Some details of the analysis are described below.

Data

The initial data acquired at the GFZ-IGS Center are the 30 sec RINEX data from 29 IGS pilot service stations collected at the network data centers CDDIS and IGN.

For the analysis itself undifferenced ionospheric free phases with a sampling rate of 6 minutes were used. P-code data entered into the analysis to preset the ambiguities. The identified ambiguities were constrained to the expected P-code accuracy. Consecutive data segments of 32 hour were formed to carry out the solutions including a quality assessment in overlapping orbital segments.

Analysis

Data from 29 globally distributed ROGUE receivers went into the solution. The solution was 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 time resolution can be chosen freely. Normal equations were combined into a yearly system to derive the global station position solution SSC(GFZ) 94 P 01. In this solution the station motions were not solved but fixed to the NUVEL-1 motion values.

The Earth Rotation Parameters (pole coordinates and length of day) were adjusted as daily values (first 24 hours of each session). These values are nearly independent from day to day. 12 hour pole values were determined in addition.

Reference Frame

CIS:	mean equator and equinox of J2000.0
Precession:	IAU 1976
Nutation :	IAU 1980
Tectonic plate model :	NNR NUVEL-1
Solid earth tides :	Wahr-model, h2=0.609, l=0.0852,permanent tide included
Ocean loading site displacement :	not applied

Dynamic Model

Gravity field:	GEM-T1 GM : 398600.4400 km^3/s^2
Velocity of light :	299792.458 km/s
Earth tides :	Wahr-model
Ocean tides :	Schwiderski-model
Corrections to rotational deformations:	C(2,0), C(2,1), S(2,1)
Indirect perturbation of oblateness of the Earth:	applied
Third body effects:	Sun, Moon, Jupiter, Venus
Solar radiation:	ROCK4 and ROCK42, including thermal reradiation (T10, T20 formulation of Fliegel [1992])
Relativistic equation of motion :	no
Tidal variations in UT1:	zonal tides with periods < 35 days

Measurement Model

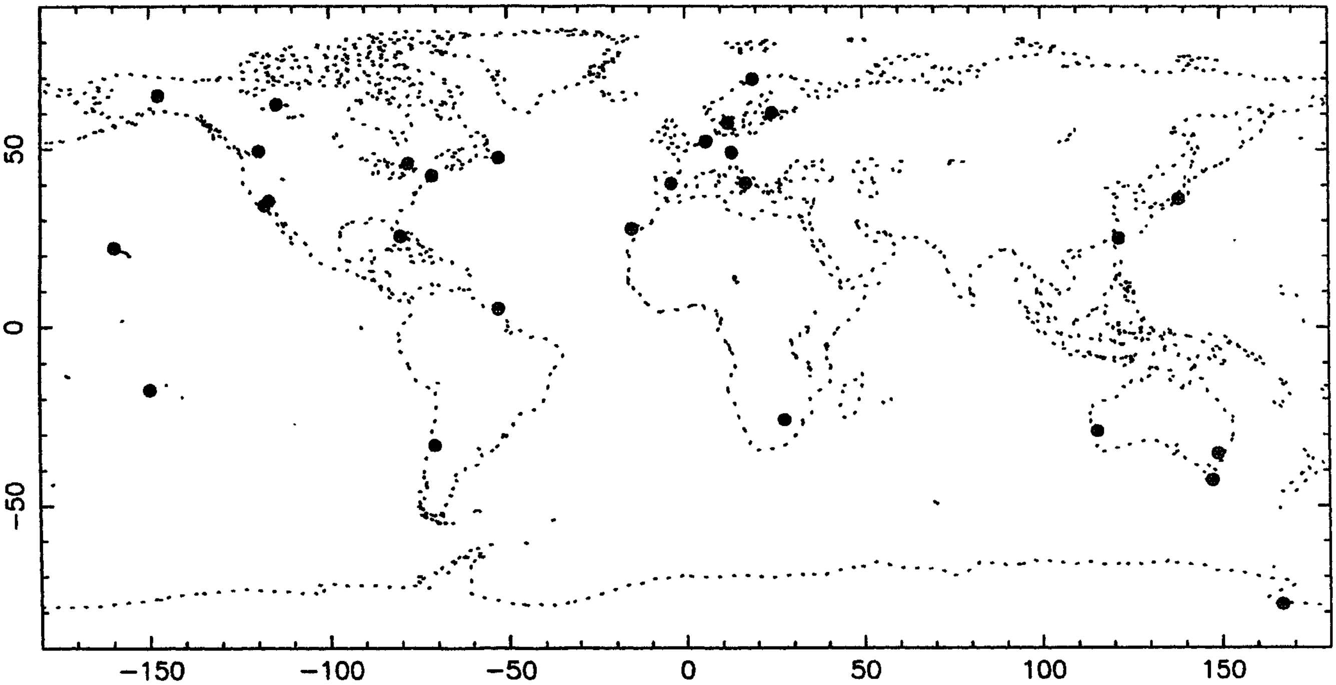
Tropospheric model :	Saastamoinen
Relativistic clock corrections :	applied
Center-of-mass corrections :	IERS Standards
GPS space vehicle masses :	from Fliegel et al. [1992] and Feltens [1991]

Solve for parameters are:

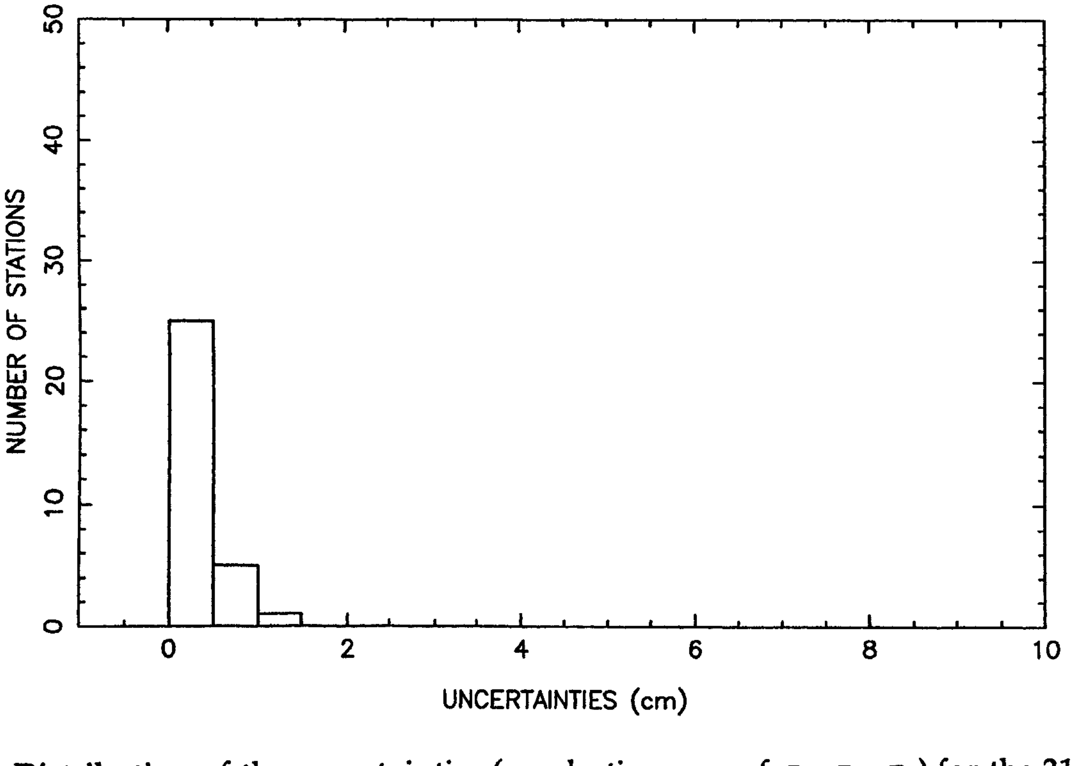
Satellite state :	32h interval
Reflectance coefficient and y-bias:	32h interval
ERP (pole and LOD) :	24h interval
Tropospheric zenith path delay:	4 h interval
Ambiguities	
Epoch time parameters	

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

1 - Technique :	GPS
2 - Analysis Center :	GFZ
3 - Solution identifier :	SSC(GFZ) 94 P 01
4 - Software used :	EPOS.P.V2
5 - Relativity Scale :	no
6 - Permanent tidal correction on station :	yes
7 - Tectonic plate model :	NNR NUVEL-1
8 - Velocity of light :	299 792 458 m/s
9 - Geogravitational constant (GMo) :	398600.4400 km^3/s^2
10 - Reference epoch :	49170 (1993.5)
11 - Adjusted parameters :	STATION COORDINATES - radius, longitude and latitude ORBIT - 6 orbital parameters - reflectance coefficient and y-bias every 32 hours EOP - daily x, y and LOD OTHER - Tropospheric zenith path delay at 4 hours intervals - Ambiguities - Epoch time parameters
12 - Definition of origin :	C(1,0)=C(1,1)=S(1,1)=0
13 - Definition of orientation :	aligned to ITRF91 by similarity transformation
14 - Constraint for time evolution :	fixed NNR-NUVEL-1



Distribution of the 28 sites of the terrestrial frame SSC(GFZ) 94 P 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 31 stations of the terrestrial frame SSC(GFZ) 94 P 01.

EOP(GFZ) 94 P 02 From Jan 1993 to Jan 1994

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1993	360	0.04	360	0.03	360	0.04

EARTH ORIENTATION RESULTS FROM THE JET PROPULSION LABORATORY USING GPS

EOP(JPL) 92 P 03

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The Satellite Geodesy and Geodynamics Group in JPL's Tracking Systems and Applications Section has continued its regular analysis of data from a globally-distributed network of Rogue GPS receivers. Using the GIPSY/OASIS-II software, estimates of a variety of parameters, including those relating to earth orientation, are made every day.

The measurements consist of undifferenced dual-frequency (1.2276 and 1.5742 GHz) carrier phase and P-code pseudorange. For both carrier phase and P-code, linear combinations of the individual frequencies provide the ionosphere-free phase and pseudorange. Data noise values for these are taken to be 1 cm and 1 m, respectively, during periods when anti-spoofing (AS) is not in effect. Data below 15 degrees elevation are not used. The phase data are decimated to 5 minutes for 93 Jan 01 - Feb 03, 10 min for Feb 04 - Oct 30, and 7.5 min beginning Oct 31. The P-code data are carrier-smoothed over the same interval.

Data corresponding to each GPS day are analyzed in 30-hour batches centered on GPS noon. Estimated parameters are satellite state vectors and solar radiation pressure, receiver coordinates, zenith wet troposphere delay at each receiver site, station and satellite clock offsets, carrier phase ambiguities, and earth orientation. A typical day's analysis of 40 stations and 26 satellites contains ~57,000 phase measurements, from which ~1550 parameters are determined (parameters allowed to vary stochastically are counted only once). The rms post-fit residuals for the phase measurements are typically a few mm. Those measurements with more than 5 cm post-fit residual for phase, or 5 m for pseudorange, are considered outliers and excluded.

The Williams solid Earth tide model is used; it differs from the IERS standards by an insignificant amount. Pole tide and the Love number variation at K1 frequency are modeled beginning Apr 01 (*IERS Technical Note 13*). Ocean loading is modeled beginning Nov 04 (Scherneck, H -G, 1991, A parametrized solid earth tide model and ocean tide loading effects for global geodetic baseline measurements, *Geophys. J. Int.*, **106**, pp 677-694; private communication between Scherneck and JPL).

The Earth's gravity field is described by the JGM1 8x8 multipole expansion using terms up through degree and order 8. The value of GM used is 398600.4415 km^3/s^2. Beginning Apr 13 the JGM2_12x12 gravity field is used [Nerem, R S, *et al.*, Gravity model development for TOPEX/Poseidon: Joint Gravity Models 1 and 2, *J. Geophys. Res.*, submitted, 1994].

Nominal values of the parameters for each GPS satellite [3 each for position and velocity, and two for solar radiation pressure (srp)] are from the broadcast ephemeris. Weak a priori constraints of 1 km and 10 mm/s for position and velocity, respectively, are imposed. The T10-T20 solar radiation pressure model is used for srp [Fliegel, H.F., Gallini, T.E., and Swift, E.R., Global Positioning System Radiation Force Models for Geodetic Applications, *J. Geophys. Res.*, **97**(B1), 1992].

Table 1 contains a list of sites from which data were used in the analysis. The number of calendar days in 1993 for which data from each site were used is also listed, together with the median (over the year) daily value of the rms post-fit residual.

Parameters are first estimated without fiducial constraints, and the station estimates and covariance are set aside. (Such daily free-network solutions form the basis for SSC(JPL) 92 P 01.) The locations of eight sites (denoted with "*" in Table 1) are then held fixed in each day's analysis to provide a reference frame for GPS satellite ephemerides and earth orientation. Up through Oct 22, locations of the fiducials are updated at the beginning of each month. Beginning Oct 23, they are updated daily. Positions and velocities are ITRF 91 [SSC(IERS) 92 C 04]. Beginning Dec 20 and later (except Dec 25), we begin to use 13 fiducials (additional five denoted with "." in Table 1) and ITRF 92. Based on two days in 1994 analyzed both ways, we observe a shift in X pole of -0.825 ± 0.005 mas and a shift in Y pole of -0.035 ± 0.175 mas (ITRF 92 - ITRF 91). Non-fiducial sites are solved for as constant parameters for each analysis day.

The wet troposphere zenith delays at each site are modeled as a random walk in time with a 1 cm^2/hour variance derivative, and are mapped to satellite elevations using the Lanyi mapping function. Their nominal values are 0.1 m at every site and are estimated with 500-m a priori constraints.

The zenith dry delays are assumed fixed for every site, and are also mapped to satellite elevations using the Lanyi mapping function. The zenith dry delay is assumed to be 2.3 m * exp (-H/Ho), where H is the height of the site and Ho = 8621 m. Because the wet and dry delays are nearly degenerate parameters, the estimated wet delay in fact represents the combined delay which deviates from the nominal wet+dry.

Clocks for all but one station and satellite are estimated as a white-noise process with updates at each new time datum. One maser-based clock is chosen as a reference. Prior to Jan 06, this was the clock at FAIR. Beginning 1993 Jan 06 and later, the reference clock is at ALGO, except on a few days when ALGO data were not available. These clocks are generally believed accurate to better than 1 μsec. The carrier phase ambiguities are estimated as real-valued parameters.

Table 1. GPS Receiver Sites Used in EOP(JPL) 92 P 03

site	country	JPL ID	rms (mm)	days
Alberthead	Canada	ALBH	5.2	347
Algonquin Park	Canada	*ALGO	4.1	364
Bermuda	North Atlantic	BRMU	6.1	255
Tdibinbilla	Australia	.CANB	5.1	361
Mammoth Lakes	Unites States	CASA	5.0	273
Fairbanks	United States	*FAIR	4.5	337
Fortelaza	Brazil	FORT	6.2	184
Greenbelt	United States	GGAO	4.3	81
Goldstone	United States	.GOLD	3.5	361
Graz	Austria	GRAZ	4.0	306
Hartebeesthoek	South Africa	*HART	5.1	357
Harvest	United States	HARV	5.2	359
Herstmonceux	United Kingdom	HERS	3.8	273
Hobart	Australia	HOBA	4.8	229
Jet Propulsion Lab	United States	JPLM	4.5	351
Kiruna	Sweden	KIRU	8.7	122
Kokee Park	United States	*KOKB	6.3	342
Kootwijk	Netherlands	.KOSG	3.6	350
Kourou	French Guiana	KOUR	7.4	330
Madrid	Spain	*MADR	4.9	364
Maspalomas	Canary Islands	MASP	5.0	348
Matera	Italy	MATE	4.0	295
McMurdo	Antarctica	MCMU	4.7	213
McDonald	United States	MDO1	4.7	182
Metsahovi	Finland	METS	3.4	343
Ny Alesund	Norway	NALL	4.3	278
North Liberty	United States	NLIB	4.5	296
Onsala	Sweden	ONSA	3.9	345
Pamatai	Tahiti	PAMA	9.1	246
Penticton	Canada	PENT	4.0	338
Pietown	United States	PIE1	4.8	326
Pinyon	United States	PINY	4.1	109
Quincy	United States	QUIN	5.2	325
Richmond	United States	RCM2	6.9	215
Richmond	United States	RCM4	6.2	62
Richmond	United States	RCM5	4.8	18
Santiago	Chile	*SANT	6.1	356
St. John's	Canada	STJO	4.8	361
Taipai	Taiwan	TAIS	5.2	344
Tromso	Norway	*TROM	3.8	357
Usuda	Japan	USUD	4.8	317
Vandenberg	United States	VNDP	4.1	295
Westford	United States	WEST	4.8	273
Wettzell	Germany	.WETB	4.4	327
Yaragadee	Australia	*YAR1	4.1	338
Yellowknife	Canada	.YELL	3.9	360

* Indicates fiducial site for entire year.
• Indicates fiducial site beginning Dec 20 (except Dec 25).

Nominal values for X and Y polar motion and UT1R-UTC, as well as the rates for these quantities, are obtained for each analysis day from the IERS Bulletin B predicted values. Estimates of polar motion are weakly (5-m) constrained, while UT1R-UTC is tightly constrained (0.01 mm) to be the nominal. Beginning Jul 11, we tightened the a priori constraints on the polar motion rate parameters to properly reflect the data strength for determining these quantities and the accuracy of the IERS Bulletin B predictions. (This applies also to Jul 07, but not to Jul 15.) LODR is estimated with a very loose a priori constraint.

All days in 1993 were analyzed, including 45 for which our AS strategy was in effect. AS periods are Feb 20-21, Feb 26 - Mar 01, Mar 31, Apr 19 - Apr 24, Apr 28 - May 03, May 06, Jun 05 - 09, Sep 17 - Sep 20, Sep 24 - Sep 28, Oct 29 - Oct 31, Nov 03-06, Nov 08-09, Nov 26, and Dec 07.

Our AS analyses exclude data below 20 degrees elevation angle. In the first half of 1993, pseudorange data were used during AS but with a 500-m data noise (increased from 1 m). Beginning with the Sep AS period, we stopped using pseudorange altogether in the parameter estimation phase of each day's analysis. Finally, beginning Oct 29, we reduced the amount of allowed stochastic variation in satellite radiation pressure parameters to a negligible level when processing data acquired during periods of AS. [Our AS strategy improves significantly in 1994.] Using Space 93 (R. Gross, submitted to IERS), we have estimated that our formal errors for pole coordinates are underestimated by a factor of 2.42 for non-AS days, and 6.38 for AS days.

For the 353 days prior to our adjustment to the new 13-station ITRF 92 reference frame, we have compared our polar motion and LODR series with those from Space 93 (using scaled formal error weighting) and IERS Bulletin B Final Values, respectively. The results are in Table 2.

Table 2: Comparison of this work with Space 93 (polar motion) and IERS Bulletin B Final values (LODR)

	weighted mean difference	weighted standard deviation
X pole (mas)	0.669	0.430
Y pole (mas)	1.432	0.274
LODR (msec)	-0.007	0.151

Pole weights are $1/(s^2)$, where s is 2.42 times the formal error for non-AS days, and 6.38 times the formal error for AS days. The LODR result is unweighted and excludes all AS days as well as 8 outliers for which the discrepancy exceeds 0.5 msec.

Acknowledgment. The work described in this report was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

EOP(JPL) 92 P 03 From Nov 1992 to Jan 1994

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	39	0.16	39	0.15	39	0.50
1993	365	0.14	365	0.15	365	0.50

SITE COORDINATES AND VELOCITIES FROM THE JET PROPULSION LABORATORY USING GPS

SSC(JPL) 94 P 01

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G. Blewitt
University of Newcastle upon Tyne

Coordinates and velocities for 41 globally distributed sites have been computed using GPS data spanning three years from January 22, 1991 through September 16, 1993. Velocity estimates for all sites are provided for the first time (Heflin *et al.*, 1993). A no-fiducial approach was used whereby all site positions and velocities were estimated, preserving the independence of the GPS solution and avoiding the possibility of systematic errors which can be caused by fiducial constraints. The four step analysis process is described below.

1. Estimate

All daily site positions were estimated using weak constraints of 10 m to 1 km for each site component. The 10 m constraint is used only for sites with well known nominal values. The GPS data span three years from January 22, 1991 through September 16, 1993 but not all sites are present for the entire time span and there is a gap where no analysis was carried out between February 13, 1991 and May 31, 1992. A typical site has data spanning about one year. Daily solutions after January 17, 1993 were products of the standard IGS processing performed at JPL. A detailed description of the strategy used is provided in the summary of EOP(JPL) 94 P 03. The number of receiver sites and satellites has increased significantly since 1991 and the analysis strategy has also evolved with time. The most significant improvements include estimation of LODR and a stochastic treatment of the satellite forces due to solar radiation pressure (Vigue *et al.* ,1993).

2. Combine

All daily solutions were combined using a standard least-squares constant-velocity model to obtain a single set of positions and velocities. Full covariance matrices were used when combining the daily solutions.

3. Constrain

Instead of using the fiducial approach, we choose to apply fourteen internal constraints to the combined covariance matrix. Internal constraints are not new and the basic idea is to fix several linear combinations of positions and velocities at their estimated values instead of fixing some number of position and velocity components at externally provided values. Internal constraints offer two significant advantages. First, they allow the GPS estimates to remain independent of other techniques and second, they avoid the possiblity of systematic effects which can be caused if there are errors in the fiducial coordinates or velocities. We have built upon the internal constraint method of Vanicek and Krakiwsky (1987) and have generalized their approach to include fourteen internal constraints and allow those constraints to be non-zero so that the final matrix is fully invertible, allowing it to be combined with other solutions.

4. Transform

We estimate seven traditional Helmert parameters and their rates to transform the GPS solution into ITRF92. The three rotations, three translations, and one scale ensure no net offset with respect to ITRF92 while the corresponding rates ensure no net drift.

Solution SSC(JPL) 94 P 01 represents a significant improvement over our previous submissions because of the increased time span of data and because all velocities are estimated. A number of geophysically interesting signals are present in this solution, including global tectonic motion, deformation in plate boundary zones, displacement due to the Lander's earthquake, volcanic uplift at CASA, and a possible detection of glacial rebound at Algonquin Park. Sites in the northern hemisphere have WRMS values 2-3 times better than those in the southern hemisphere. The overall CHI^2/DOF is 0.34, indicating that the errors as stated are too conservative by about a factor of 1.7 and the mean residual WRMS values over all sites are 6 mm, 9 mm, and 14 mm for latitude, longitude, and height respectively.

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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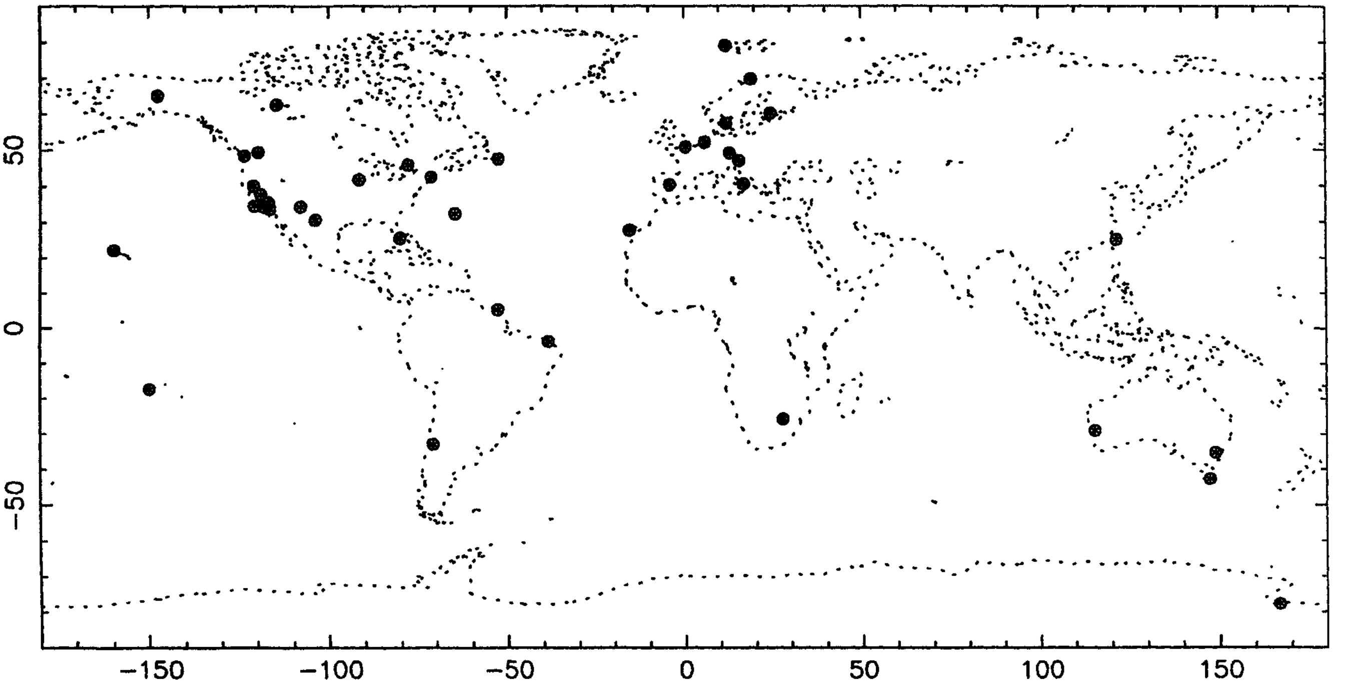
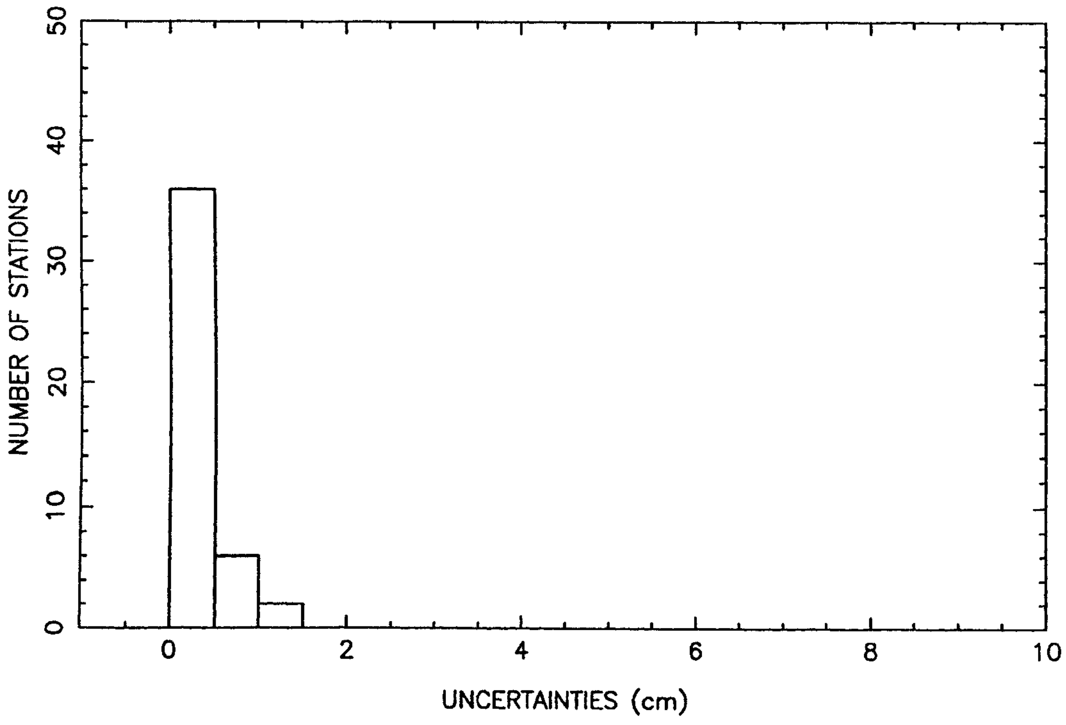
Summary description of the terrestrial system attached to the set of station coordinates and velocities SSC(JPL) 94 P 01:

1 - Technique:	GPS
2 - Analysis Center:	JPL
3 - Solution identifier:	SSC(JPL) 94 P 01 (JPL Identifier JGC9401)
4 - Software used:	GIPSY
5 - Relativity scale:	Local Earth Scaled into ITRF92
6 - Permanent tide correction on station:	No
7 - Tectonic plate model:	None
8 - Velocity of light:	299792458 m/sec
9 - GM:	3.986004415 10^{14} m^3 s^{-2}
10 -Reference epoch:	1992.5
11 -Adjusted parameters:	All station coordinates X, Y, Z PMX, PMY, and LODR All satellite epoch states Three stochastic solar pressure parameters per satellite Random walk zenith tropospheric delays for each site All clocks except one Real valued carrier phase ambiguities
12 - Definition of origin:	Translated into ITRF92
13 - Definition of orientation:	Rotated into ITRF92
14 - Constraint for time-evolution:	All velocities estimated Fourteen parameter transformation ensures no net drift with respect to ITRF92



Distribution of the 40 sites of the terrestrial frame SSC(JPL) 94 P 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 44 stations of the terrestrial frame SSC(JPL) 94 P 01.

NOAA EARTH ORIENTATION TIME SERIES FROM GPS OBSERVATIONS

NOAA 94 P 02, 03, 04

M.S. Schenewerk, G.L. Mader, W. Kass, R. Dulaney, D. Pursell

DESCRIPTION OF ANALYSIS PROCEDURES

Daily terrestrial site coordinates and a time series of polar motion parameters have been estimated using tracking data from a subset of the International GPS Service (IGS) tracking network selected to provide timely data, global coverage, and a consistent set of GPS antennas. The a priori ephemerides were created with ARC, an orbit integrator program, provided by the Massachusetts Institute of Technology. ARC employs an eleventh order Adams-Moulton predictor-corrector to produce satellite positions and partial derivatives to the initial conditions at 22.5 minute intervals. The constants used in the program were defined in the IERS standards [McCarthy, 1989]. An 8x8 gravity field taken from the GEM-L2 model were used from January 1, 1993 to November 30, 1993; thereafter, an 8x8 gravity field from the GEM-T2 [Marsh *et al.*, 1989] were used. A simplified ROCK4T model [Columbo, 1989] for the satellite radiation pressure, ad hoc Y-bias, and the related partial derivatives were used throughout 1993. Conversion between inertial and earth-centered, earth-fixed coordinates uses the IGS Rapid Service Earth Orientation Values provided by the National Earth Orientation Service (NEOS), and nutation values generated from IAU 1980 Theory of Nutation [Seidelmann, 1982; Wahr, 1981]. In routine production initial conditions taken from the previous day's adjusted ephemeris are used, although any precise or broadcast ephemeris can provide these.

The creation of databases, the identification and removal of cycle slips, and orbit adjustment were accomplished using software developed at NOAA. The program PAGE3 combined the a priori ephemerides from ARC with tracking data in a least-squares adjustment to produce the adjusted ephemerides, polar motion, and other estimates. 24 hours of tracking data were used for each set of daily estimates. A 15 degree observation elevation cutoff was imposed. Dual frequency phase data were combined to produce an ionosphere-free, double-differenced observable. Double-differencing effectively removes all clock errors. S/A, which manifests itself as a satellite clock error, is therefore also removed with this technique. A daily neutral atmosphere path length correction derived from the Saastamoinen dry atmosphere [Saastamoinen, 1972] plus the Chao wet atmosphere [Chao, 1972] zenith corrections combined with the Center for Astrophysics 2.2 mapping function [Davis *et al.*, 1985], and an Earth tide correction [Melchior, 1978] for the tracking sites are applied. No atmospheric or ocean loading corrections were applied. Sites coordinates, all satellite positions and velocities, scale factors for the radiation pressures, Y- biases, and tropospheric delays, phase bias values, and adjustments to the Earth's rotational pole position were estimated.

From January 13, 1993 to November 30, 1993, the following 13 sites with well determined coordinates [Bock, 1992] were held fixed:

Algonquin, Canada,
Kokee Park, HI, USA,
Matera, Italy,
Metsahovi, Finland,
Taiwan, Tai-Shi,
Wettzell, Germany,
Yellowknife, Canada.
Fairbanks, AK, USA.
Kootwijk Obs., Netherlands,
McMurdo, Antarctica,
Onsala, Sweden,
Tromso, Norway,
Yarragadee, Australia,

The coordinates for these fixed sites were updated on April 30, 1993 [Bock, 1993] and resulted in a break in the polar motion time series. On December 1, 1993, the set of 13 tracking sites and coordinates selected by the IGS to be held fixed or tightly constrained were implemented resulting in a second break in the polar motion time series. The coordinates for these sites are consistent with the ITRF91. These 13 sites are:

Algonquin, Canada,
Goldstone ,CA, USA,
Kokee Park, HI, USA,
Madrid, Spain,
Tidbinbilla, Australia,
Wettzell, Germany,
Yellowknife, Canada.
Fairbanks, AK, USA,
Hartebeesthoek, S. Africa,
Kootwijk Obs., Netherlands,
Santiago, Chile,
Tromso, Norway,
Yarragadee, Australia,

References

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Chao, C. C., 1972: A Model for Tropospheric Calibration from daily Surface and Radiosonde Balloon Measurements, Tech. Memo Calif. Inst. Technol. Jet Propul. Lab., 17.

Columbo, O., 1989: Private Communication.

Davis, J. L., *et al.*, 1985: Geodesy by radio interferometry: Effects of atmospheric modeling errors on estimates of baseline length, *Radio Science*, 20, 6, 1593-1607.

Marsh, J. G., *et al.*, 1989: The GEM-T2 Gravitational Model, NASA Technical Memorandum 100746.

McCarthy, D. D., ed.,1989: IERS Standards (1989), *IERS Technical Note* 3, Observatoire de Paris, Paris.

Melchior, P., 1978: The Tides of the Planet Earth, Pergamon Press, p. 109-121.

Saastamoinen, J., 1972: Atmospheric correction for the troposphere and stratosphere in radio ranging of satellites, *The Use of Artificial Satellites for Geodesy, Geophys. Monogr. Ser.*, **15**, ed. S. W. Henriksen et al., AGU, Washington, D. C., p. 247-251.

Seidelmann, P. K., 1982: Theory of the Rotation of the Rigid Earth, *Celestial Mechanics*, **15**, 277-326.

Wahr, J. M., 1981: The Forced Nutations of an Elliptical Rotation Elastic, and Oceanless Earth, *Geophys. J. Roy. Astron. Soc.*, **64**, 705-727.

EOP(NOAA) 94 P 02 From Jan 1993 to Apr 1993

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

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1993	104	0.09	104	0.09

EOP(NOAA) 94 P 03 From Apr 1993 to Nov 1993

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

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1993	215	0.10	215	0.10

EOP(NOAA) 94 P 04 From Dec 1993 to Dec 1993

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

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1993	31	0.08	31	0.09

Summary description of the solutions EOP (NOAA) 94 P 02, 03 and 04

1 - Technique :	GPS, Double-differenced phase
2 - Analysis center :	NOAA
3 - Solution identifier :	Daily
4 - Software used :	ARC orbit integrator; PAGE3 for data analysis
5 - Relativity Scale :	Terrestrial site coordinates are geocentric
6 - Permanent tidal correction on station :	No correction is applied to remove the zero-frequency displacement introduced by the solid Earth tide model.
7 - Tectonic plate model :	ITRF92 velocity field (combined solution from SLR and VLBI estimates) for all fixed sites except for TROMSO, YELLOWKNIFE, and SANTIAGO from December 1, 1993 - December 31, 1993 where the NNR-NUVEL1 is used.
8 - Velocity of light (C) :	299792458. m/s
9 - Geogravitational constant (GMo) :	$3.9860044451 \times 10^{14}$ m^3/s^2 January 13, 1993 - November 30, 1993; $3.98600436 \times 10^{14}$ m^3/s^2 December 1, 1993 - December 31, 1993.
10 - Reference epoch :	48829.5 January 13, 1993 - November 30, 1993; 48850.6 December 1, 1993 - December 31, 1993.
11 - Adjusted parameters :	XYZ geocentric station coordinates for all non-fixed sites; pole X and Y coordinates; 1 tropospheric scale factor; double differenced phase biases. All parameters estimated once per day.
12 - Definition of the origin :	Origin specified by the combined solution from SLR and VLBI estimates.
13 - Definition of the orientation :	not applicable
14 - Constraint for time evolution :	Origin specified by the combined solution from SLR and VLBI estimates.

1991-1993 SIO POLAR MOTION SERIES

SIO 93 P 01

The implementation of this series is described in IERS Technical Note No 14, p. P-43.

EOP(SIO) 93 P 01 From Aug 1991 to Jan 1994

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

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1991	140	0.39	140	0.43
1992	332	0.19	332	0.20
1993	365	0.09	365	0.09

SATELLITE LASER RANGING

EARTH ORIENTATION AND STATION COORDINATES FROM THE CENTRAL LABORATORY FOR GEODESY ANALYSIS: 1984-1991

CLG 94 L 01, 02, 03

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Acad. G. Bontchev str., bl. 1 , 1113 Sofia, Bulgaria

Analysis of 454293 Lageos normal points, collected by the global SLR tracking network between January 1984 and December 1991 was done. It was based on fitting the orbit in 30(31) day arcs. Estimating the Earth orientation and force model parameters at different intervals (Table 1), three solutions were derived. The monthly arcs were combined to form the basis for the global parameters determination. A set of 59 station positions at epoch 1984.0 and 47 station horizontal velocities were obtained. EOP were modeled as constants over their intervals of validity. LODR series were calculated by forward differencing of the estimated UT1R values (fixing each month the first 5 day UT1 at IERS). Improved version of the least-squares orbital analysis program SLRP-3 (Satellite Laser Ranging data Processor) was used for the data processing.

Table 1. Solutions Design

Adjusted Parameters	Interval of Validity or Estimated: Yes/No L 01	L 02	L 03
Orbital State Vector	30	30	30
Solar Radiation Coefficient	30	30	15
Along Track Acceleration	30	30	15
EOP: Xp, Yp, LODR	5	5	3
Station Positions	Yes	Yes	Yes
Station Velocities	No	Yes	Yes
Love and Shida Numbers	No	Yes	Yes
Geogravitational Parameter	Yes	Yes	Yes
Selected Set of Geopotential Coefficients: C(2,0),C(3,0), C(4,0),C(2,1),S(2,1),C(3,1), S(3,1),C(4,1),S(4,1),C(2,2), S(2,2),C(3,2),S(3,2),C(4,2), S(4,2)	No	Yes	Yes

MODELS AND CONSTANTS

Reference Frame

CIS:	mean equator and equinox of J2000.0
Planetary Ephemeris:	JPL DE200/LE200
Initial Earth Orientation:	BIH Circular D, 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 20x20, with GM=398600.436 km^3/s^2 and a=6378137 m as scale parameters with the geopotential coefficients and GM=38600.4418 km^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:	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:	IERS Standards

DATA

LAGEOS normal points generated from full rate data received from GAOUA (1984-1988) and from GFZ (1989-1991) were used. All data are equally weighed.

CONSTRAINTS

The first 5 days value of UT1-UTC in each arc fixed at BIH (IERS). The latitude and longitude of 7105 and the latitude of 7210 fixed at ITRF91. The latitude and longitude rates for 12 sites fixed at NNR-NUVEL1 velocities.

The estimated EOP, station coordinates, station velocities and correlation matrices have been provided to the IERS Central Bureau.

References

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

Summary description of the solutions CLG 94 L 01, L 02 and L 03

1 - Technique:	SLR
2 - Analysis Center:	CLG
3 - Solution Identifier:	SSC(CLG) 94 L 01, L 02, L03
4 - Software Used:	SLRP-3
5 - Relativity Scale:	Geocentric (LE)
6 - Permanent Tidal Correction on Station:	No
7 - Tectonic Plate Motion Model:	NNR-NUVEL1
8 - Velocity of Light:	299792458 m/s
9 - Geogravitational Constant:	398600.4418 km^3/s^2
10 - Reference Epoch:	1984.0
11 - Adjusted Parameters:	Orbit: 6 cartesian elements every 30(31) days. Radiation pressure coefficient and along track acceleration every 30(31) days in L01 and L 02 or every 15 days in L 03. Stations: Epoch 1984.0 geodetic station positions for 59 sites. Latitude and longitude rates for 47 sites in L 02, L 03. EOP: Xp, Yp and LODR every 5 days in L01 and L 02 or every 3 days in L 03. Geopotential: Geogravitational constant and selected set of 15 geopotential coefficients in L 02 and L 03. Solid Earth Tides: Love and Shida numbers in L 02 and L 03.
12 - Definition of Origin:	Geocentric, C(1,0)=C(1,1)=S(1,1)=0.
13 - Definition of Orientation:	A priori EOP values from BIH Circular D or IERS Bulletin B. Fixed longitude and latitude of 7105, fixed latitude of 7210.
14 - Constraint for Time Evolution:	Latitude and longitude rates for 12 sites fixed to NNR-NUVEL1.

EOP(CLG) 94 L 01 From Jan 1984 to Dec 1991

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1984	72	0.50	72	0.48	52	0.16
1985	81	0.43	81	0.41	57	0.14
1986	77	0.50	77	0.43	53	0.15
1987	78	0.42	78	0.40	56	0.14
1988	77	0.39	77	0.39	53	0.13
1989	78	0.47	78	0.46	54	0.17
1990	78	0.38	78	0.42	54	0.14
1991	77	0.46	77	0.44	53	0.15

EOP(CLG) 94 L 02 From Jan 1984 to Dec 1991

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1984	72	0.48	72	0.45	52	0.15
1985	81	0.41	81	0.39	57	0.14
1986	77	0.48	77	0.41	53	0.14
1987	78	0.40	78	0.38	56	0.14
1988	77	0.37	77	0.37	53	0.13
1989	78	0.45	78	0.44	54	0.16
1990	78	0.37	78	0.40	54	0.14
1991	77	0.44	77	0.43	53	0.15

EOP(CLG) 94 L 03 From Jan 1984 to Dec 1991

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1984	107	0.59	107	0.52	87	0.28
1985	119	0.50	119	0.46	95	0.25
1986	114	0.58	114	0.48	90	0.27
1987	117	0.48	117	0.47	95	0.27
1988	118	0.47	118	0.46	94	0.24
1989	118	0.57	118	0.52	94	0.33
1990	119	0.45	119	0.50	95	0.26
1991	119	0.53	119	0.51	95	0.27

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

CSR 94 L 01

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Earth orientation parameters were derived from a combination of Lageos full rate and quick look data. Full rate data was used from 1976 until the end of June, 1991, and quicklook data was used for July 1991 through February 1994. Mean positions for all sites were adjusted and horizontal 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 force and measurement models used for this solution conform generally to the IERS Standards, with the following exceptions:

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 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 NUVEL-1 NNR.

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

7) Diurnal and semidiurnal fluctuations 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 unmodelled 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 17 February 1994, a period of 17.8 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 solved. The UT1 estimates are obtained from the Lageos node residuals, with the constraint that they follow the JPL SPACE93 series at periods longer than about 60 days [Gross, 1994].

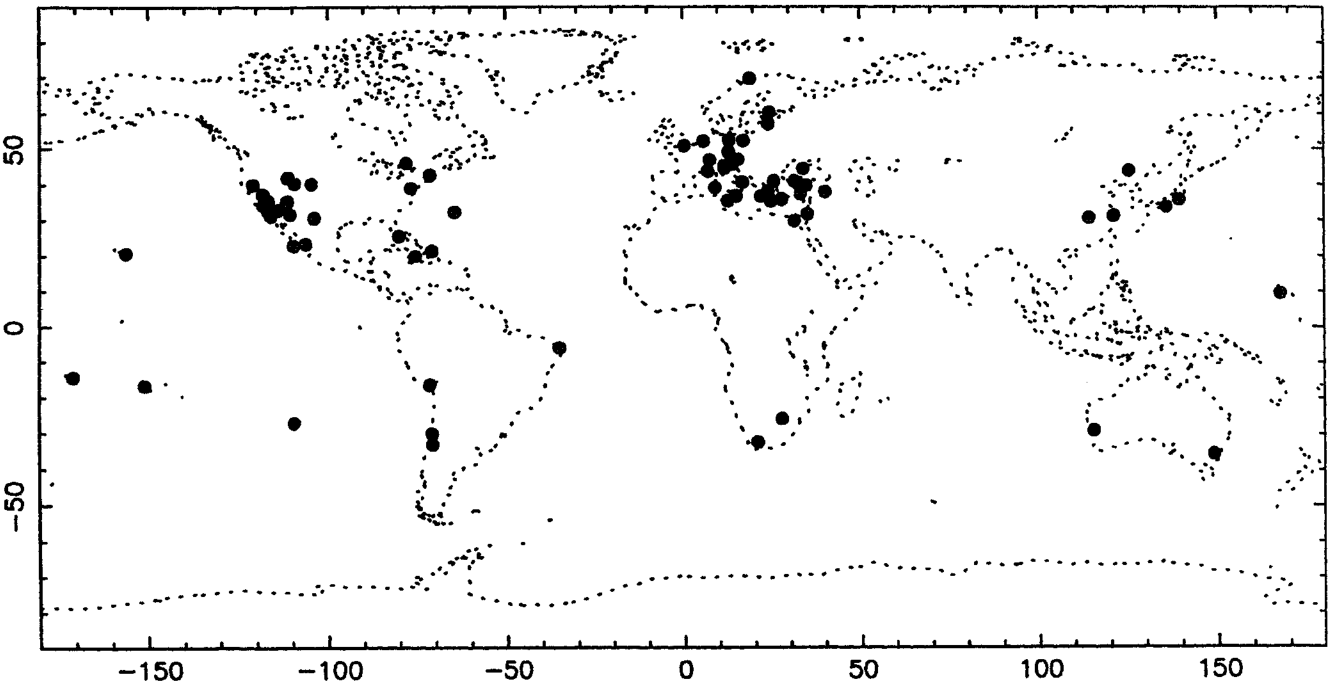
References

Gross, R.S., 1994: A Combination of Earth Orientation Data: SPACE93, *IERS Technical Note 17*, Observatoire de Paris, Paris, p. C-5.

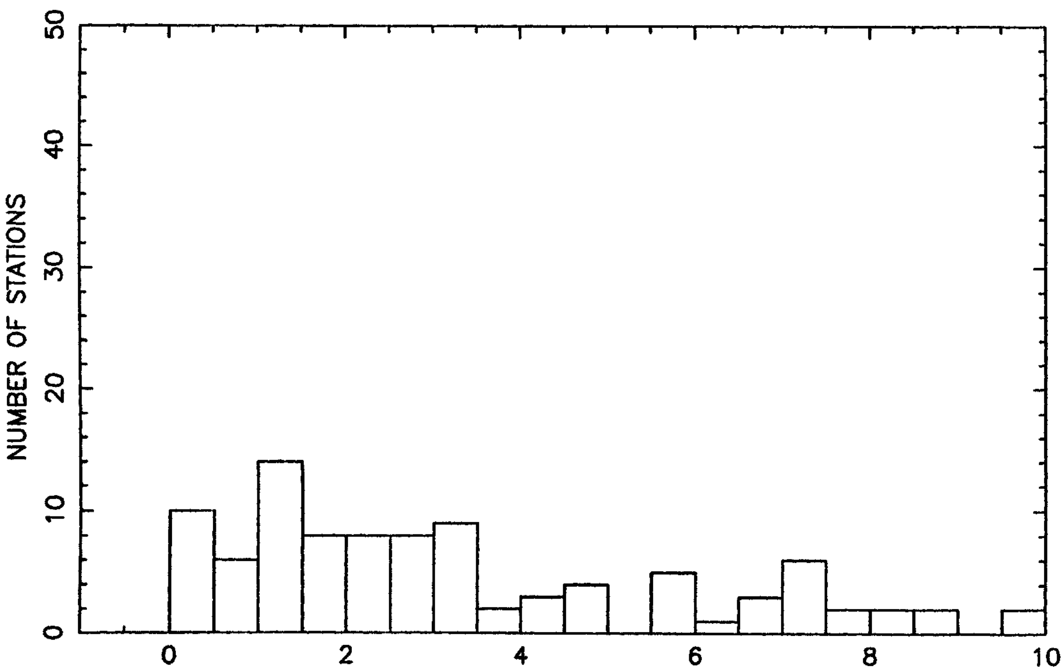
Summary description of the solution CSR 94 L 01

1 - Technique:	SLR
2 - Analysis Center:	CSR
3 - Solution Identifier:	SSC(CSR) 94 L 01
4 - Software Used:	UTOPIA
5 - Relativity Scale:	Geocentric (LE)
6 - Permanent Tidal Correction on Station:	Tidal correction has nonzero mean. Positions do not reflect true mean.
7 - Tectonic Plate model:	NUVEL-1 NNR
8 - Velocity of light (C) :	299792458 m/sec
9 - Geogravitational constant (GM) :	398600.4415 km^3/s^2
10 - Reference Epoch :	1988.0
11 - Adjusted Parameters:	
Coordinates:	Epoch 1988.0 position for all sites in cartesian coordinates solved one time for entire data span. Horizontal velocities adjusted for 47 selected sites.
Site dependent biases:	Adjusted where necessary.

Orbit:	6 Keplerian mean element corrections to long arc orbit solved every 3 days throughout span subject to constraint that posteriori uncertainties were less than specified values. If not satisfied, interval was extended in multiples of 3 days until solution was acceptable.
EOP:	x, y and UT1 (UT1 constrained by JPL SPACE93) were solved at the same intervals as the orbit.
12 - Definition of the origin:	Geocentric, C10 = C11 = S11 = 0.0
13 - Definition of the orientation:	System oriented to agree with EOP(CSR) 93 L 02 maintained through fixing the latitude and longitude of site 7210 (HOLLAS) and the latitude of site 7105 (GRF105).
14 - Constraint for time evolution:	Latitude and longitude rate of site 7210 (HOLLAS) and latitude rate of site 7105 (GRF105) fixed to NUVEL-1 NNR velocities. Horizontal site velocities adjusted with a priori sigma of 100 mm/yr for the other sites with sufficient data. Because of weak SLR data from Mojave (7288) and Owens Valley (7853) their velocity adjustment was constrained using a priori sigma of 5 mm/yr.



Distribution of the 72 sites of the terrestrial frame SSC(CSR) 94 L 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 116 stations of the terrestrial frame SSC(CSR) 94 L 01. 21 stations with uncertainties larger than 10 cm are not shown.

EOP(CSR) 94 L 01 From May 1976 to May 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
1976	33	12.72	33	14.38	33	7.46
1977	71	12.87	71	12.06	71	6.82
1978	72	12.06	72	10.29	72	6.56
1979	76	9.38	76	9.71	76	6.01
1980	117	5.47	117	3.48	117	3.11
1981	112	5.40	112	3.20	112	2.72
1982	113	3.60	113	2.76	113	2.38
1983	118	3.08	118	2.67	118	1.86
1984	121	1.22	121	1.09	121	1.12
1985	121	1.07	121	0.90	121	0.94
1986	122	0.88	122	0.82	122	0.92
1987	122	0.60	122	0.56	122	0.77
1988	122	0.50	122	0.53	122	0.71
1989	121	0.53	121	0.51	121	0.75
1990	122	0.50	122	0.52	122	0.74
1991	122	0.62	122	0.62	122	0.75
1992	122	0.61	122	0.59	122	0.76
1993	122	0.50	122	0.40	122	0.30
1994	49	0.50	49	0.50	49	0.30

EARTH ROTATION AND STATION COORDINATES COMPUTED FROM SLR AND GPS OBSERVATIONS

EOP(DUT) 94 L 01
SSC(DUT) 94 C 01

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The solution ERP(DUT) 94 L 01 consists of a coherent set of Earth Rotation Parameters (ERPs), determined from SLR observations on LAGEOS-1 taken in the period September 1983 to December 1992 at a frequency of once per 3 days. An essential element of this computation is the development of a model for instantaneous station positions, SSC(DUT) 94 C 01, which is a combined solution based on the SLR observations already mentioned and GPS measurements taken in the periods May 16 - 28, 1989, and July 29 - August 3, 1992.

The computation of ERPs 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.

For the derivation of the model for station positions, the 9.3 year interval covered by the SLR observations was divided into 38 consecutive sub-intervals, with a length of 13 weeks on average. Independent network solutions were computed for each of these sub-intervals. The parameter estimation was based on a weighted least-squares fit of the satellite orbit to the observations. To limit the effect of potential dynamic model errors, the analysis programs GEODYN-2 and SOLVE-2 were executed in a so-called multi-arc mode, where each sub-interval was further divided into a series of consecutive 7-day data arcs and satellite parameters (state-vector at epoch, a constant along-track acceleration and a 1-cpr radial acceleration) were estimated for each individual data arc.

In addition to the station positions, ERP solutions were derived simultaneously. Please note that this is not ERP(DUT) 94 L 01. To prevent numerical singularities, the parameters were constrained in a Bayesian way. The a priori standard deviation of the pole position and UT1 were assigned values of 100 marcsec and 10 ms, respectively, with a priori values taken from the IERS (EOP) 90 C 04 solution. The initial station coordinates, computed during a preliminary data screening run, were given an a priori uncertainty of 1 m. The ascending nodes of the satellite state-vectors were kept fixed at the values determined in the same data screening. The interval June - December 1985 was not analyzed because measurements in a form suitable for the analysis were not available. The SLR computation model is summarized in Table 1a.

Table 1a: Models and constants (SLR component).

DYNAMIC MODEL:	
Gravity field	NASA/CSR JGM-1 model, truncated at 20x20
GM	398600.4415 km^3/s^2
c	299792.458 km/s
ae	6378.1363 km
1/f	298.2564
Solid earth tides	Wahr model
Ocean tides	NASA/CSR JGM-1 model
Solar radiation	CR fixed at 1.13; occultation by Earth and Moon; umbra and penumbra
Along-track acceleration	constant value; adjusted
Radial acceleration	sine and cosine 1cpr term; adjusted
Third body attraction	Sun, Moon, Venus, Mars, Jupiter, Saturn; positions from JPL DE200/LE200 ephemeris
Pole tide (dynamic part)	applied
REFERENCE FRAME:	
Station coordinates	adjusted (step 1); SSC(DUT) 94 C 01 (step 2)
Earth rotation	adjusted at 3-day intervals; a priori values from IERS (EOP) 90 C 04
CIS	mean equator and equinox of J2000.0
Precession	IAU 1976 (Lieske model)
Nutation	IAU 1980 (Wahr model)
Plate motion	not applied (step 1); close to NUVEL-1 NNR (step 2)
Tidal uplift	h2 = 0.609, l2 = 0.0852
Pole tide (geometric part)	applied
Ocean loading	not applied
Atmospheric pressure loading	not applied
MEASUREMENT MODEL:	
Observations	Release B normal points, computed at NASA (September 1983 - May 1985), DGFI (January - October 1986, 1987), DUT (November, December 1986) and ATSC/BFEC (1988 - 1992)
Data weighting	determined from overall model accuracy and system characteristics
Tropospheric refraction	Marini-Murray model

The information on the terrestrial network was further augmented by the addition of two solutions based on GPS observations. These contributions were computed from data taken during the EUREF-89 and IGS EPOCH92 campaigns. The results from these analyses proved valuable for the European part of the station network, particularly for the Italian, Greek and Turkish stations. The computation model used for the reduction of the GPS observations is summarized in Table 1b.

Table 1b: Models and constants (GPS component).

DYNAMIC MODEL:	
Gravity field	NASA/GSFC GEM-T3 model, truncated at 8x8
Solar radiation	Rock-4 for Block I and Rock-42 for Block II satellites
Third body attraction	Sun and Moon; positions from JPL DE200/LE200 ephemeris
REFERENCE FRAME:	
Station coordinates	a priori values from ETRF 89 (EUREF 89) and ITRF 92 (EPOCH92)
CIS	mean equator and equinox of J2000.0
Tidal uplift	h2 = 0.609, l2 = 0.0852
Ocean loading	not applied
Receiver clocks	Kootwijk reference
MEASUREMENT MODEL:	
Observations	Data sampled at 1 point / 6 minutes; ionosphere-free linear combinations of the pseudorange and carrier phase observations (i.e. P3 and L3)
Data weighting	1.0 m for pseudoranges; 1.0 cm for carrier phases
Tropospheric refraction	nominal zenith delay (dry component); nominal zenith delay (10 cm), adjusted using random-walk model (wet component); Lanyi model for elevation mapping

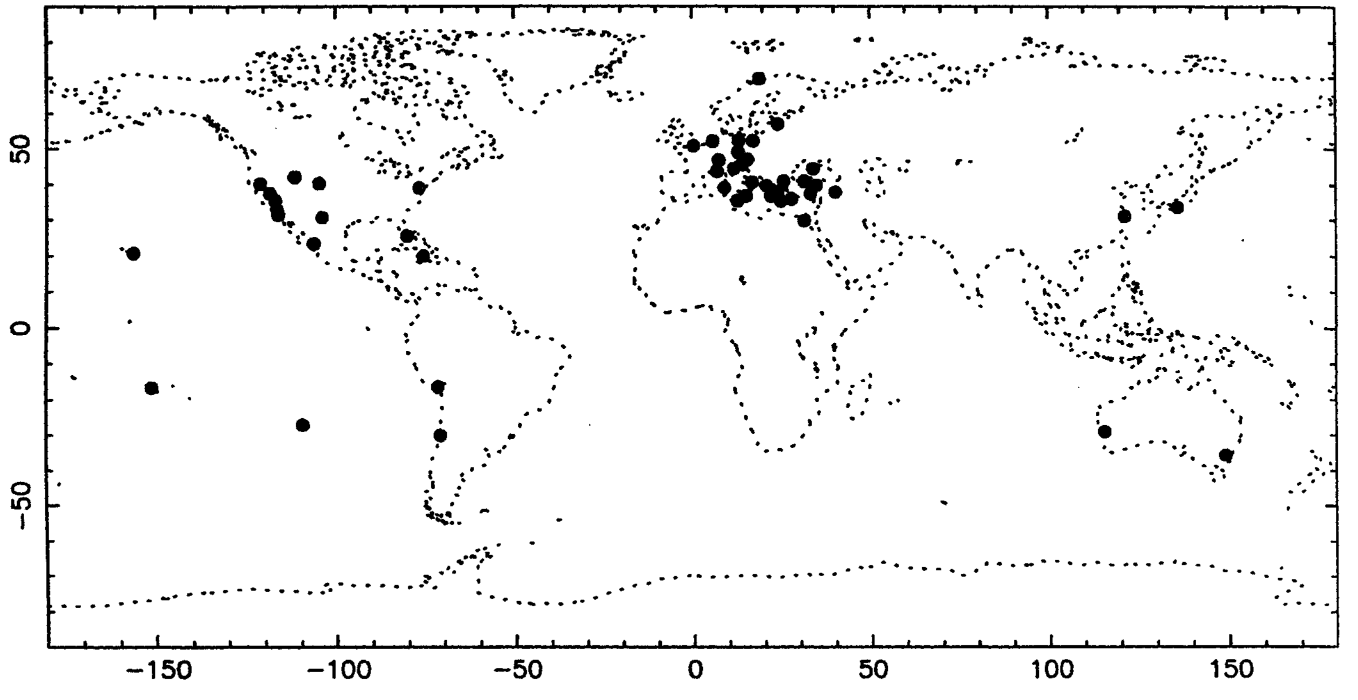
The final element of the first step was the conversion of the series of network solutions (40 in total) into a coherent model for the description of the station positions as a function of time. This model consists of initial coordinates for the geodetic monument at epoch (January 1, 1988) plus time-derivatives of these. In the computations, Helmert parameters, absorbing systematic differences in scale (GPS only), orientation and origin, were estimated for all individual network solutions but one. To avoid numerical instabilities, the motion of 12 stations was constrained with a standard deviation of 1 mm/yr to the a priori value which was taken from the NUVEL-1 No Net Rotation model. The remainder of the parameters were adjusted freely.

In the second step, the resulting model for instantaneous station positions was back-substituted into the previous step: the GEODYN/SOLVE computations were repeated, but now with these station positions held fixed and the pole position and UT1 parameters estimated freely. Because of the limited time-span covered by the GPS observations (19 days in total, divided over two campaigns), this second step was executed for the SLR component only. The computation model used here is listed in Table 1, and is identical to the one used for the SLR component of step 1. It closely follows the IERS Standards, with few exceptions: (i) the JGM-1 solution, both for the gravity field and for the ocean tides, was used instead of the advised GEM-T1 and Schwiderski models; (ii) the effect of ocean loading and atmospheric pressure loading on station positions was not applied; (iii) no plate motion was applied during each sub-interval; and (iv) new values for GM, ae and the flattening of the Earth were used. Details of the terrestrial system are given in the summary description below.

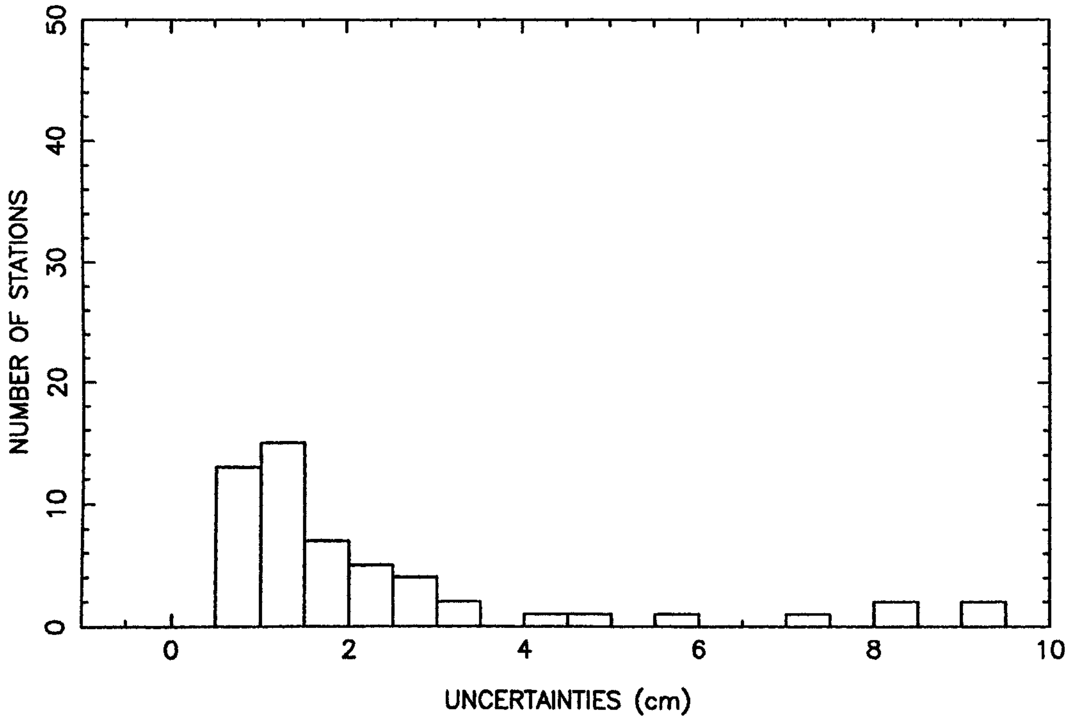
The solution for each station consists of the cartesian monument coordinates at epoch, the corresponding standard deviations (both in m), the apparent motions and the standard deviations of the latter (in m/yr). The reference epoch of the solution is January 1, 1988.

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

1 - Technique	combined SLR and GPS
2 - Analysis center	DUT
3 - Solution identifier	SSC(DUT) 94 C 01
4 - Software used	GEODYN-2/SOLVE-2/GIPSY
5 - Relativity scale	local Earth
6 - Tidal uplift	yes
7 - Tectonic plate model	NUVEL-1 NNR for selected sites (Yarragadee, Easter Island, Greenbelt, Platteville, Huahine, Mazatlan, Maui, Wettzell, Graz, RGO, Orroral Valley, Kootwijk); DUT solutions derived for the remainder of the stations, determined w.r.t. a reference frame moving according to NUVEL-1 NNR
8 - Velocity of light	299792.458 km/s
9 - Gravitational constant	398600.4415 km^3/s^2
10 - Reference epoch	January 1, 1988
11 - Adjusted parameters	X0, Y0, Z0 (for selected stations); X0, Y0, Z0, Xdot, Ydot, Zdot (remainder)
12 - Origin definition	C(1,0) = C(1,1) = S(1,1) = 0
13 - Orientation definition	initial coordinates at reference epoch
14 - Evolution constraint	NUVEL-1 NNR (for selected stations); DUT apparent motions (remainder)



Distribution of the 49 sites of the terrestrial frame SSC(DUT) 94 C 01.



Distribution of the uncertainties (quadratic mean of $\sigma_x, \sigma_y, \sigma_z$) for the 59 stations of the terrestrial frame SSC(DUT) 94 C 01. 5 stations with uncertainties larger than 10 cm are not shown.

EOP(DUT) 94 L 01 From Sep 1983 to Dec 1992

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	0.44	39	0.43	39	0.33
1984	120	0.35	120	0.30	120	0.28
1985	48	0.48	48	0.34	48	0.33
1986	117	0.29	117	0.26	117	0.23
1987	119	0.26	119	0.23	119	0.21
1988	122	0.27	122	0.26	122	0.22
1989	119	0.24	119	0.22	119	0.20
1990	122	0.22	122	0.21	122	0.17
1991	120	0.25	120	0.24	120	0.20
1992	120	0.23	120	0.23	120	0.19

EARTH ROTATION AND TERRESTRIAL REFERENCE FRAME FROM LAGEOS I AND II OBSERVATIONS

EOP(GAOUA) 94 L 01
SSC(GAOUA) 94 L 02

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Solution GAOUA 94 L 01 consists of a set of 89 station coordinates, velocities of 45 sites, having good observing history, as well as a corresponding set of Earth rotation parameters. Analysis is based on Lageos I normal points spanning the period from September 1983 through October 1993 (48007 passes) and Lageos II normal points from November 1992 through October 1993 (4666 passes) using software package Kiev-Geodynamics-5.

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

- gravity field and ocean tides are modelled according to GSFC/CSR UT JGM-2 model truncated at 20x20;
- nutation corrections are according to McCarthy *et al.* (1991)

For the analysis the whole interval of data was divided into 15 day arcs and on the first step only the orbits of LAGEOS I & II were adjusted on each of these arcs. On the second step the combination of 15-day arcs yielded the final solution, consisting of the parameters listed in the summary sheet below.

Earth rotation parameters (x, y and UT1) were adjusted at daily intervals. In the case of poor data distribution or lack of observing stations, ERPs were held fixed to EOP(IERS) C 04 (about 15% of data). Despite this procedure there are still some spurious data caused probably by the bad geometry of the observing network. It should be noted that adding LAGEOS II data resulted in an improvement of the formal error of the ERPs by a factor of 1.5 even though the orbit of this satellite is modelled a bit worse than that of LAGEOS I.

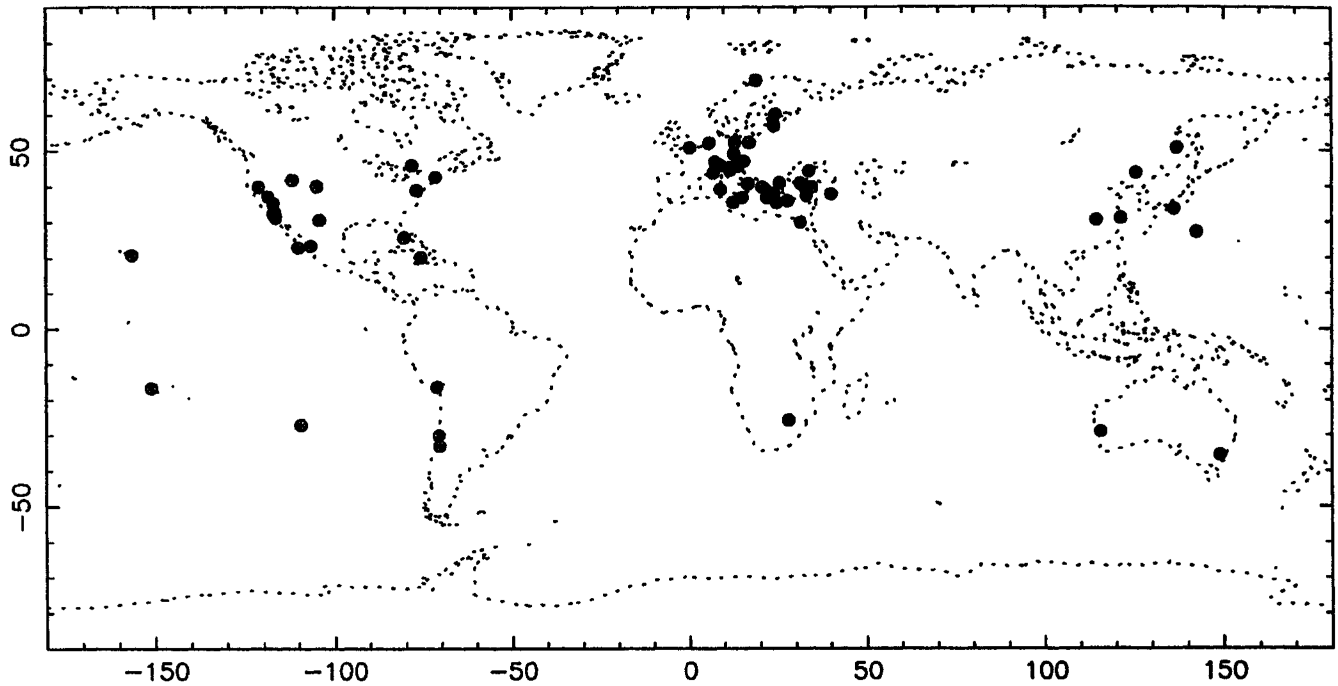
The terrestrial reference system is attached to ITRF91 by fixing the latitude of station 7105 and the longitude and latitude of station 7210. Time evolution of the system is modelled by NUVEL-1 NNR for sites with either poor data distribution or short-term activity periods. The velocities of 45 sites (59 collocated stations) have been estimated and linked to NUVEL-1 NNR through 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 1988.0 (MJD 47161). Separate estimation of station positions using LAGEOS I and LAGEOS II data shows up to 5 cm difference in translational components of transformation between reference frames and up to 0".0009 in rotational components. The scale difference is about 4 ppb.

References

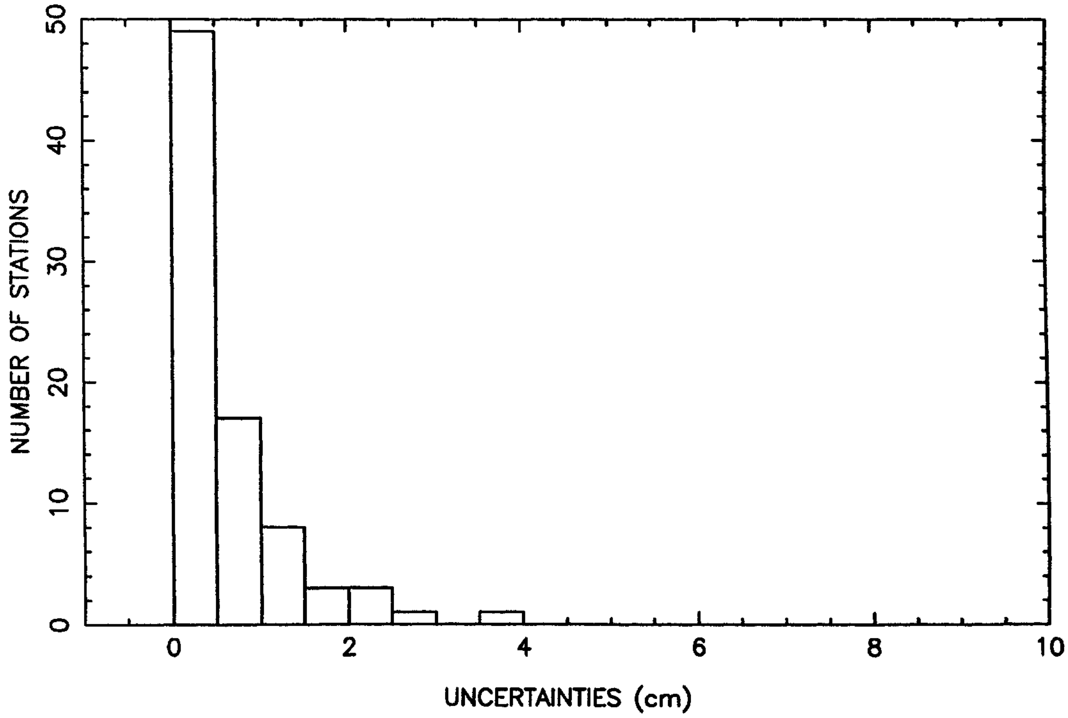
McCarthy, D.D., and Luzum, B.J., 1991: Observations of Luni-solar and Free Core Nutation, *Astron. J.*, **102**, 1889-1895.

Summary sheet for the description of the solutions GAOUA L 01 and L 02

1 - Technique :	SLR to LAGEOS I & II
2 - Analysis Center :	GAOUA
3 - Solution identifier :	SSC(GAOUA) 94 L 01
4 - Software used :	KIEV-GEODYNAMICS - 5
5 - Relativity scale :	LE
6 - Permanent tidal correction on station :	YES
7 - Tectonic plate model :	NUVEL-1 NNR
8 - Velocity of light (C) :	299 792 458
9 - Geogravitational constant (GM) :	3.9860 04415 10^{14}
10 - Reference epoch :	MJD 47161 (1988.0)
11 - Adjusted parameters :	
Coordinates:	X,Y,Z for 89 stations Xdot, Ydot, Zdot for 45 sites
Orbit :	5 keplerian mean elements estimated every 3 days, Ct and Cr every 15 days
EOP :	Xp, Yp, UT1-UTC every 1 day
12 - Definition of the origin :	C10=C11=S11=0
13 - Definition of the orientation :	ERP values from EOP(IERS) 90 C 04 Longitude and latitude of station 7105 and latitude of station 7210 fixed.
14 - Constraint for time evolution :	Fixed plate motion model for stations with unsufficient data or short observing history. Latitude and longitude rate of station 7105 and latitude rate of station 7210 fixed to NUVEL-1 NNR velocities.



Distribution of the 63 sites of the terrestrial frame SSC(GAOUA) 94 L 02.



Distribution of the uncertainties (quadratic mean of $\sigma_x, \sigma_y, \sigma_z$) for the 84 stations of the terrestrial frame SSC(GAOUA) 94 L 02. 2 stations with uncertainties larger than 10 cm are not shown.

EOP(GAOUA) 94 L 01 From Sep 1983 to Oct 1993

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	78	0.90	78	0.90	78	0.68
1984	272	0.70	272	0.60	272	0.57
1985	280	0.70	281	0.60	281	0.54
1986	297	0.60	296	0.60	297	0.51
1987	314	0.60	314	0.50	314	0.48
1988	314	0.50	314	0.50	314	0.47
1989	295	0.60	295	0.60	295	0.50
1990	309	0.50	309	0.50	309	0.47
1991	293	0.60	293	0.60	293	0.49
1992	323	0.60	323	0.60	323	0.50
1993	294	0.50	294	0.40	294	0.37

STATION COORDINATES AND EARTH ROTATION PARAMETERS BASED ON LAGEOS LASER RANGING

EOP(GFZ) 94 L 01, 02, 03, 04
SSC(GFZ) 94 L 01

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Summary

On the basis of Satellite Laser Ranging (SLR) data till Mid-August, 1993, an improved Set of Station Coordinates SSC (GFZ) 94 L 01, including site motions was determined, and four series of Earth Rotation Parameters (ERP) with time resolutions of 5 days (ERP (GFZ) 94 L 01, main solution), 3 days (L02), 2 days (L03) and 1 day (L04) have been produced.

Model parameters and data

In continuation of the former years solutions (Montag *et al.*, 1993) an improved Set of Station Coordinates (SSC) and four sets of Earth Rotation Parameters (ERP) with different time resolution were determined. The constants and model parameters implemented in the GFZ software package EPOS.P.V1 used for the multistage-multiarc parameter estimation procedure conform to the IERS Standards (McCarthy (Ed.), 1992) with the following exceptions:

- tidal variations in UT1 caused by zonal tides with periods larger than 35 days not considered,
- nutation corrections derived by VLBI included,
- GEM-T1 instead of T3 applied.

The normal points for both LAGEOS 1 and LAGEOS 2 were used until August 10, 1993 (MJD 49209). For the new time interval from Sept. 92 to Aug. 93 altogether 8780 passes (4960 of LAGEOS 1 and 3820 of LAGEOS 2) with 12800 normal points (62300 of LAGEOS 1 and 58500 of LAGEOS 2) from 36 stations were included in the analysis.

Set of station coordinates and velocities

The Set of Station Coordinates SSC (GFZ) 94 L 01 was determined from LAGEOS 1 data over the whole 13 years time interval. It contains 103 marker positions at 71 stations. For 46 stations (69 markers; colocated markers at one station were constrained (with weight of 105) to have the same velocities) the data distribution was good enough to adjust the site motions simultaneously. For the other stations the velocities were held fixed to those of the NUVEL-1 no net rotation model (de Mets *et* *al.*, 1990). In the summary description below some details on the adopted model for the terrestrial system are given. The site positions were refered to epoch 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 the station 7105. Additionally, no common net rotation was permitted in relation to the reference coordinate set SSC (GFZ) 93 L 01 (also ITRF 89). Corrections due to the permanent tidal deformation of the Earth were applied. The given mean errors for SSC (GFZ) 94 L 01 have been scaled by a factor of 5, because the obtained formal errors seem to be too optimistic. The errors for the velocities were defined to be zero for all stations which were fixed to the NUVEL-1 velocity model.

Earth rotation parameters

Based on the set of station coordinates SSC (GFZ) 94 L 01 with adjusted site velocities four sets of ERP (pole coordinates and length of day - LOD) with different time resolutions were determined. The main solution ERP (GFZ) 94 L 01 has a time resolution of 5 days. Additionally two series with a time resolution of 3 days (ERP (GFZ) 94 L 02) and 2 days (ERP (GFZ) 94 L 03) were derived. These series beginning in 1980 and the 1-day resolution series (ERP (GFZ) 94 L 04) beginning in 1983 are now all updated till August, 1993. Because, contrary to the L01 solution, the LOD results for the L02, L03 and L04 solutions were not estimated directly but via UT1, the time epochs have to be transferred for the LOD values by - 1.5 d, - 1.0 d and - 0.5 d, respectively. 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. No post-adjustment smoothing or filtering procedure was applied. The formal errors (standard deviation) of the pole coordinates and the LOD are rather optimistic, generally. Compared to the solutions of the past years the inclusion of LAGEOS 2 data did not essentially increase the precision. They are ± 0.1 mas for the pole coordinates with a time resolution of 5d and 3d, ± 0.15 mas for a time resolution of 2 days and ± 0.2 mas for pole coordinates with a 1-day time resolution. The precision estimates of LOD are ± 0.006 ms, ± 0.01 ms and ± 0.02 ms, respectively. The formal error of LOD with a time resolution of 5 days (± 0.006 ms) was scaled by a factor of 4 in order to make it comparable with the other ones determined via UT1.

The accuracy is mostly influenced by the data density and distribution. Therefore it could be improved by including LAGEOS 2 data. In cases of poor data density and distribution the errors can increase several times. If the data density is poor, problems can especially arise for high resolution results. Then also the correlations between the estimated ERP become very high. This fact was used as an automatical elimination criterion (if higher 0.9). As an average about 3 per cent of the results with a time resolution of 2d and 15 per cent of 1-day resolution results were eliminated. With the additional LAGEOS 2 data the accuracy could be improved by a factor of about 1.5. The errors are now smaller than ± 1 mas for the pole coordinates with a time resolution of 5d and about ± 1.5 mas for 1-day resolution results. In the case of LOD it ranges between ± 0.07 ms (5d resolution) and ± 0.15 ms (1d). With the improved accuracy due to the inclusion of LAGEOS 2 data an essential decrease of the scattering of the ERP differences between different solutions is associated. Displaying e.g. the differences between our 5-day solution and the IERS combined solution the smaller scattering after the addition of LAGEOS 2 data is evident. Additionally, the differences between our solution ERP (GFZ) 94 L 01 on one hand and our solutions L02, L03 and L04 on the other hand (Table 1) show a decrease of the scattering (r.m.s deviation from the mean) by 30 to 60 per cent.

Table 1. Scattering of the differences between different GFZ solutions before and after including LAGEOS 2 data

	ERP (GFZ) 94 Solutions								
	L01-L02			L01-L03			L01-L04		
	x_p mas	y_p mas	LOD µs	x_p mas	y_p mas	LOD µs	x_p mas	y_p mas	LOD µs
LAGEOS1	±0.77	±0.86	±70	±1.09	±0.95	±78	±1.35	±1.57	±143
LAGEOS1+2	.51	.37	44	.68	.51	59	.85	.66	103

Conclusion

As a contribution to the realization and monitoring of the terrestrial reference frame an improved set of station coordinates including site motions and several sets of earth rotation parameters were derived. The series of ERP show a good agreement with the previously reported series and with IERS results in the overlapping zones. Comparing with the solutions from last year, the addition of LAGEOS 2 data brought a significant improvement in the accuracy for the ERP series. With the prolongation of the LAGEOS 2 data series in the next years essential improvements can also be expected for the determination of site motions as part of the set of station coordinates.

References

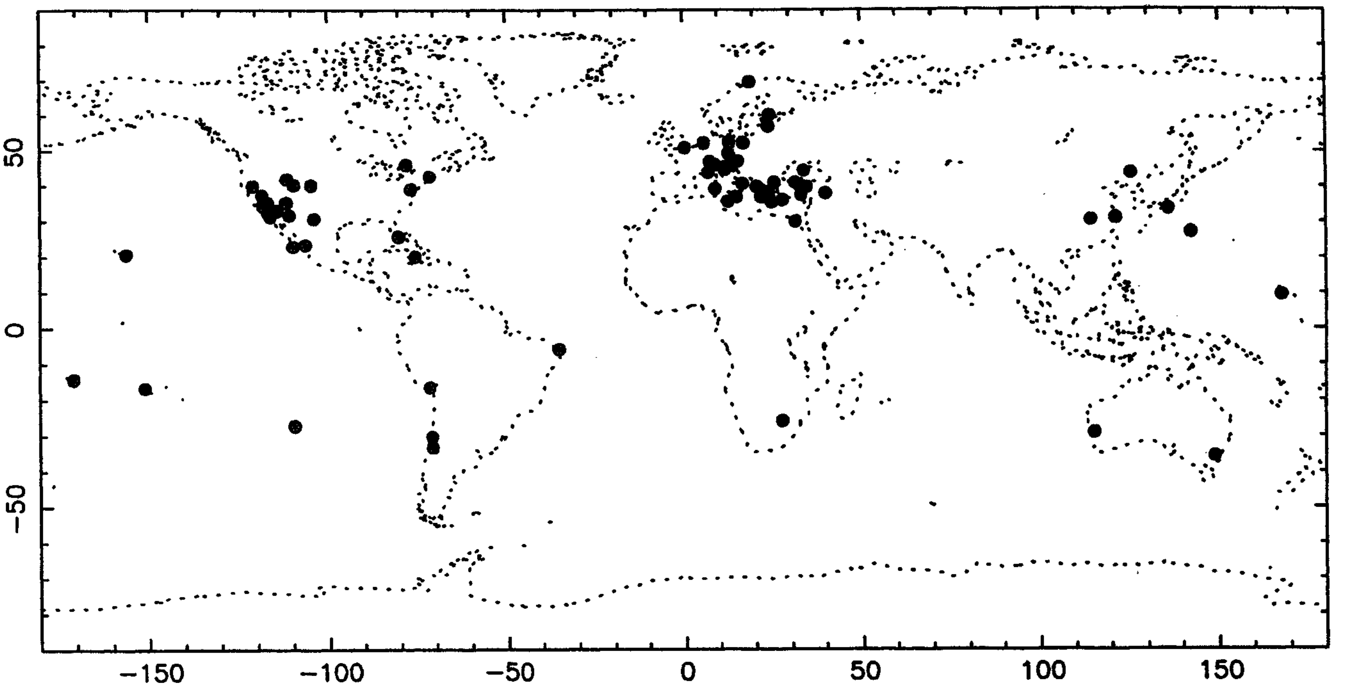
DeMets, C., Gordon, R.G., Argus D.F., and Stein, S., 1990: Current plate motions, *Geophys. J. Int.*, **101**, 425-478.

McCarthy, D.D. (ed.), 1992: International Earth Rotation Services Standards (1992), *IERS Technical Note No. 13*, Observatoire de Paris, Paris.

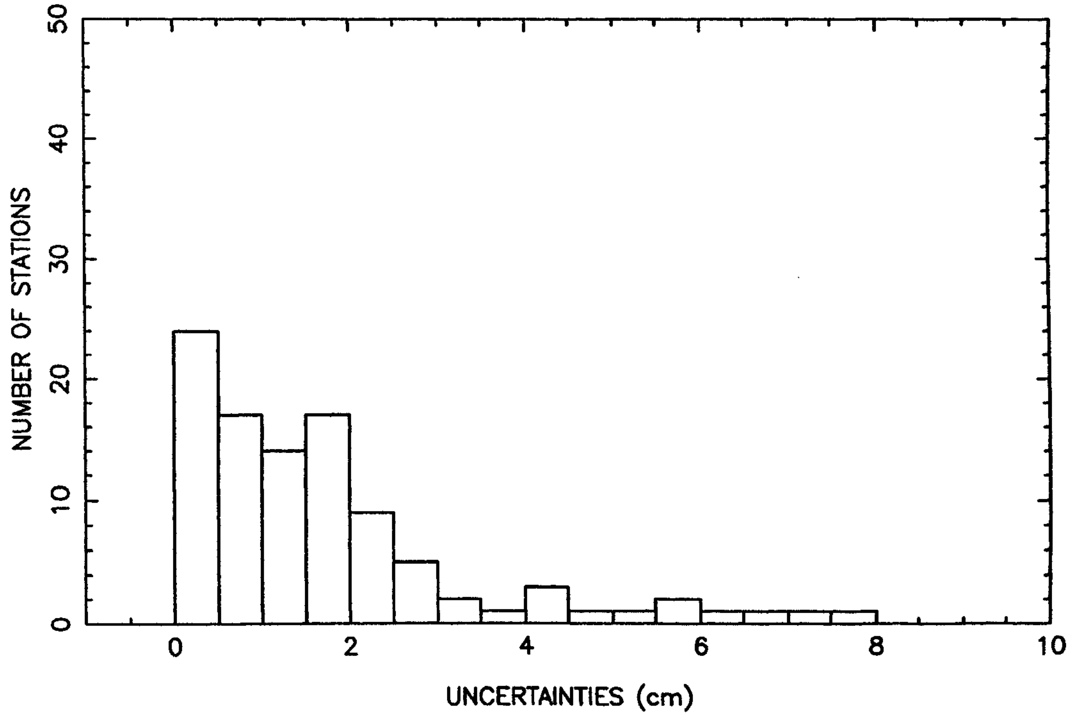
Montag, H., Gendt, G., Dick, G., Reigber, Ch., Nischan, Th., Sommerfeld, W., 1993: Earth Rotation Parameters and Station Coordinates by LAGEOS Laser Ranging Data Updated till Mid September, 1992, *IERS Technical Note No. 14*, Observatoire de Paris, Paris,L23-L30.

Summary description of the solutions GFZ 94 L 01, 02, 03 and 04

1 - Technique:	SLR
2 - Analysis Center:	GFZ
3 - Solution Identier:	SSC (GFZ) 94 L 01
4 - Software Used:	EPOS.P.V1
5 - Relativity Scale:	Geocentric (LE)
6 - Permanent Tidal Correction on station:	Yes
7 - Tectonic Plate model:	adjusted, partly NUVEL-1
8 - Velocity of light (C):	299792458 m/sec
9 - Geogravitational constant (GM):	adjusted to 398600.451km^3/s^2
10 - Reference Epoch:	1988.0 (MJD 47160.)
11 - Adjusted Parameters:	
Coordinates:	radius, longitude and latitude for all sites plus velocities in each of the coordinates, all solved one time for the whole data span
Orbit:	6 Keplerian mean elements for intervals of 5 days
EOP:	x, y and LOD, solved at 5-day intervals (the same as orbit) x, y and UT1, solved at 1-, 2- and 3-day intervals (the orbit is solved for 6 days)
12 - Definition of the origin:	Geocentric, C10 = C11 = S11 =0
13 - Definition of the orientation:	System oriented by fixing: - the latitude of 7105, 7840 - the longitude of 7840
14 - Constraint for time evolution :	no net rotation by fixing NUVEL-1 velocities for: - the latitude of 7105, 7840 - the longitude of 7840



Distribution of the 70 sites of the terrestrial frame SSC(GFZ) 94 L 01.



Distribution of the uncertainties (quadratic mean of $\sigma_x, \sigma_y, \sigma_z$) for the 102 stations of the terrestrial frame SSC(GFZ) 94 L 01. 2 stations with uncertainties larger than 10 cm are not shown.

EOP(GFZ) 94 L 01 From Jun 1991 to Aug 1993

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1991	39	0.09	39	0.09	39	0.04
1992	73	0.10	73	0.09	73	0.04
1993	44	0.10	44	0.08	44	0.04

EOP(GFZ) 94 L 02 From Jun 1991 to Aug 1993

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1991	65	0.12	65	0.13	65	0.05
1992	122	0.14	122	0.13	122	0.05
1993	74	0.14	74	0.12	74	0.05

EOP(GFZ) 94 L 03 From Jun 1991 to Aug 1993

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1991	92	0.15	92	0.15	92	0.08
1992	180	0.17	180	0.15	180	0.09
1993	108	0.17	108	0.14	108	0.08

EOP(GFZ) 94 L 04 From Jun 1991 to Aug 1993

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1991	161	0.18	161	0.17	161	0.18
1992	336	0.22	336	0.18	336	0.21
1993	217	0.20	217	0.18	217	0.20

EARTH ORIENTATION FROM GSFC SOLUTION SL8.5

GSFC 94 L 01

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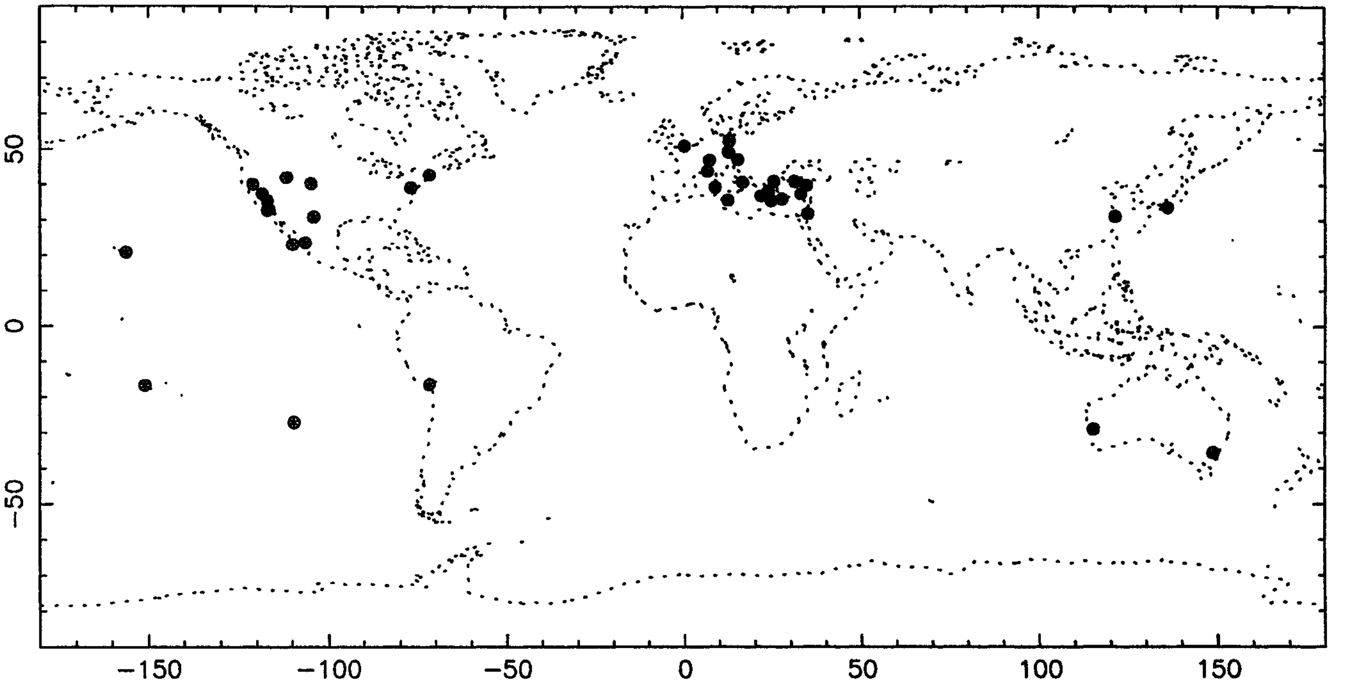
The SL8.5 solution was obtained by fitting data from LAGEOS II between November 1992 and December 1993, and LAGEOS I between January 1980 and December 1993 in 30 day (and occasionally 35 day) arcs using normal points from the global SLR tracking network. The monthly arcs were combined to derive a set 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 of 398600.4415 km^3/s^2 were adopted.

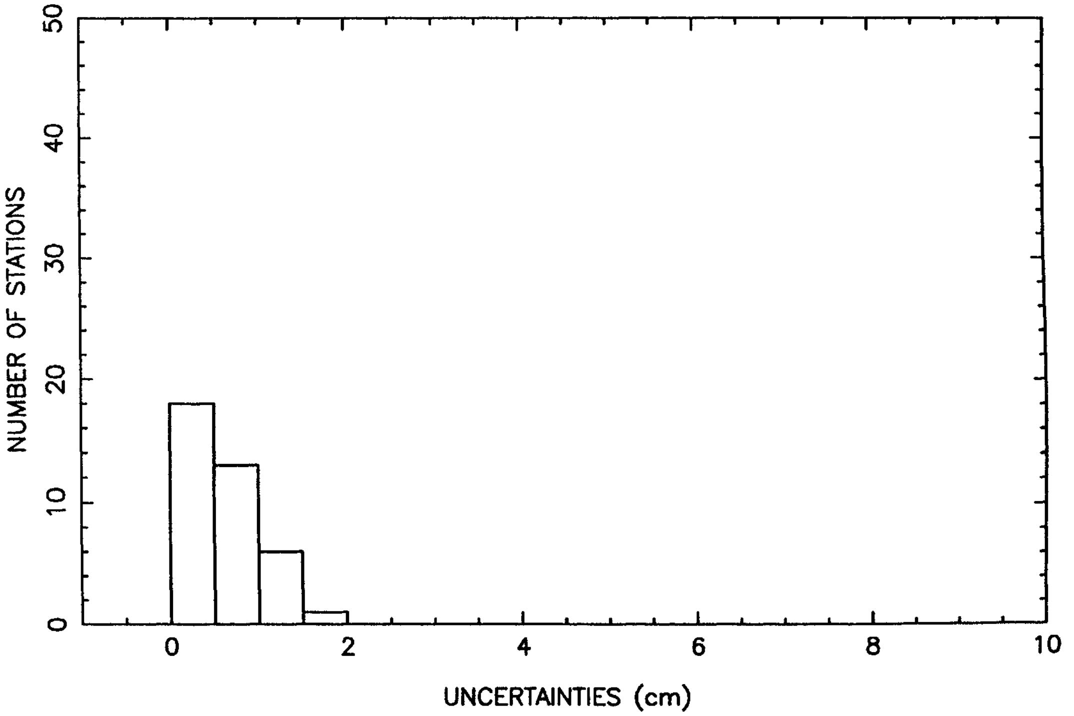
The EOP series from this solution was edited by means of a "Vondrak"-smoothing procedure using an epsilon value of 100. The resulting series are identical to the "raw" series except for the few cases where some spurious values were substituted with values interpolated from adjacent data points. This 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.

Summary description of the solution GSFC 94 L 01

1 - Technique:	SLR data to LAGEOS I and LAGEOS II
2 - Analysis Center:	NASA/GSFC
3 - Solution Identifier:	GSFC SL8.5
4 - Software Used:	GEODYN II and SOLVE II
5 - Relativity Scale:	Local Earth
6 - Station Tidal Correction:	Earth tides and Ocean loading (Scherneck)
7 - Tectonic plate model:	GSFC SL8.5
8 - Velocity of light:	299792458 m/s
9 - GM:	398600.4415 km^3/s^2
10 - Reference epoch:	880101
11 - Adjusted Parameters:	
Orbit:	6 elements every 30(35) days, along track acceleration twice per arc, once per revolution acceleration twice per arc.
Stations:	position and velocity estimated except lat, lon of Washington and lat of Maui and lat rate, lon rate of Washington and lat rate of Maui
EOP:	Xp, Yp, UT1 every 5 days from 800101 to 821228, every day from 821229 to 931231, one UT1 value fixed at IERS each month
12 - Definition of Origin:	Geocentric
13 - Definition of Orientation:	a priori ERP from IERS 90 C 04 and fixed station components
14 - Constraint for time evolution:	lat, lon rate of Washington and lat rate of Maui



Distribution of the 38 sites of the terrestrial frame SSC(GSFC) 94 L 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 38 stations of the terrestrial frame SSC(GSFC) 94 L 01.

EOP(GSFC) 94 L 01 From Jan 1980 to Dec 1993

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
1980	74	1.21	74	0.46	74	0.90
1981	73	0.55	73	0.32	73	0.40
1982	75	0.66	75	0.57	75	0.90
1983	365	0.82	365	0.81	365	0.70
1984	366	0.50	366	0.44	366	0.50
1985	365	0.47	365	0.41	365	0.40
1986	365	0.47	365	0.39	365	0.40
1987	365	0.38	365	0.35	365	0.40
1988	366	0.39	366	0.38	366	0.40
1989	364	0.40	364	0.38	365	0.40
1990	365	0.35	365	0.37	365	0.40
1991	365	0.48	365	0.45	365	0.50
1992	366	0.40	366	0.39	366	0.40
1993	364	0.30	364	0.27	364	0.30

EARTH ORIENTATION AND STATION COORDINATES FROM LAGEOS LASER RANGING

SHA 94 L 01

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The solutions EOP(SHA) 94 L 01 and SSC(SHA) 94 L 01 were derived from Lageos normal point data. The Lageos normal point data from Dec.27,1992 to Jun.24, 1993 came from the GSFC. The 180-day Lageos NP data was divided into two 90-day interval parts. A multistage multiarc method was used to estimate simultaneously satellite states, EOPs and some station coordinates. The station coordinates, as the global parameters, are adjusted in the whole long arc (90-day interval). The satellite states (position vector and velocity vector), as the first-stage local parameters, are independently adjusted in the different subarc (10-day interval). The EOPs, as the second-stage local parameters are independently adjusted in a sub-subarc (5-day interval).

The convergent criterion of the solutions in the whole long arc was that the change of satellite position in a subarc is not larger than 0.05 m and the relative error of residual mean error in a subarc is not larger than 0.005. There are mean positions for stations at epoch 1988.0 in SSC(SHA) 94 L 01. The positions of all stations refer to the optical axis of the laser ranging system.

Each set of EOP solution includes three earth orientation parameters Xp, Yp, and DR. In our solution the overall RMS fit of the laser observations to the orbits is less than 10 cm. Most of the station coordinates of SSC(SHA) 94 L 01 were adjusted except the latitude and longitude of station 7840 (RGO) and the latitude of station 7105 (GRF105).

The force and measurement models used for this solution adhere closely to the IERS standards (McCarthy, 1992).

Reference frame

- Mean equinox and equator of J 2000.0
- Station coordinates SSC(SHA) 91 L 01
- IAU 1976 precession
- IAU 1980 nutation
- DE200/LE200 planetary ephemerides
- TAI as the coordinate time scale of the earth-centered frame

Force model

- GEM-T1 earth gravity field with C(2,1) and S(2,1) of IERS standards, GM=398600.436 km^3/sec^2
- Luni-Solar and planetary gravity perturbation
- Wahr solid earth tides
- Schwiderski ocean tides
- Solar radiation pressure (Cr adjusted)
- Drag-like perturbation (Cd adjusted)
- Atmospheric tide
- Earth's radiation pressure
- General relativistic perturbation (geocentric frame)

Measurement model

- Marini Murray refraction model
- Solid earth tides displacement
- Ocean loading site displacement
- Relativistic correction

References

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

Summary description of the solution SHA 94 L 01

1 - Technique:	SLR
2 - Analysis Center:	SHA
3 - Solution Identifier:	SSC(SHA) 94 L 01
4 - Software Used:	SHORDE-1
5 - Relativity Scale:	Geocentric (LE)
6 - Permanent Tidal Correction on Station:	No
7 - Tectonic Plate model:	NNR-NUVEL1
8 - Velovity of light(C):	299 792 458 m/sec
9 - Geogravitational constant (GM):	398600.436 km^3/s^2
10 - Reference Epoch:	1988.0
11 - Adjusted Parameters:	
Coordinates:	X,Y,Z for 21 stations
Orbit:	6 Keplerian mean elements, and Ct and Cr estimated every 10 days
EOP:	Xp,Yp, and Dr every 5 days
12 - Definition of the origin:	Geocentric, C10 = C11 = S11 = 0
13 - Definition of the orientation:	System oriented by fixing: - the latitude of 7105,7840 - the longitude of 7840
14 - Constraint for time evolution:	Latitude and longitude rate of station 7840 and latitude rate of station 7105 fixed to NNR- NUVEL1 velocities

EOP(SHA) 94 L 01 From Dec 1992 to Jun 1993

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	1	60.83	1	86.14	1	0.34
1993	35	46.39	35	42.90	35	0.18

COMBINATION

COMPILED CATALOGUE OF POSITIONS OF EXTRAGALACTIC RADIO SOURCES GAOUA 94 C 01

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Following the procedure for compiling the catalogue of extragalactic radio sources (RS) proposed by Yatskiv and Kuryanova (1990), a new version of this catalogue designated RSC(GAOUA) 94 C 01 has been constructed. The catalogue contains 504 radio sources. Estimates of internal accuracy of positions of RS and relative orientation of this catalogue with respect to other compiled catalogues are given.

Introduction

Application of the Very Long Baseline Interferometry technique (VLBI) to the determination of angular positions of radio sources has marked a new step in establishing and constructing the inertial reference frame (IRF), namely, its radioastronomical realization IRF-R. In comparison with the well-known stellar IRF realization, IRF-R has a number of advantages, which determine its stability (the extragalactic radio sources are very distant objects, and their proper motions can be neglected) and internal consistency (to one millisecond of arc). At the present time, there are several IRF-R realizations represented as sets of radio source coordinates (RSC). Original (individual) RSC catalogues obtained after reduction of VLBI observations are distinguished from compiled RSC catalogues constructed by amalgamating the original ones. The first group comprises the RSC catalogues prepared at the Goddard Space Flight (GSFC), the National Oceanic and Atmospheric Administration (NOAA), etc. Efforts have been made recently to construct compilation RSC catalogues in order to diminish positional random errors and extend IRF-R on more objects. There is a series of compiled catalogues of RS positions constructed by the International Earth Rotation Service (RSC(IERS)), Astronomische Rechen Institute in Heidelberg (CC(H.G.Walter, 1991)), and by the Main Astronomical Observatory, AS Ukraine (RSC(GAOUA)). The mutual disagreement of these compiled RSC systems is on the level of one millisecond of arc, and it can be explained by different composition of the individual catalogues and by using different methods for the compilation. Following the procedure for compiling the catalogue of RS proposed by the authors earlier (Yatskiv and Kuryanova, 1990), a new version of this catalogue, designated RSC(GAOUA) 94 C 01, has been constructed.

On the construction of the compiled catalog of radio sources RSC(GAOUA) 94 C 01

The catalog is based on the individual catalogs obtained in 1993 at the Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), the National Oceanic and Atmospheric Administration (NOAA), the United States Naval Observatory (USNO) and the Geodetic Institute of the University of Bonn (GIUB). Some information about these catalogs, provided by IERS, is given in Table 1.

Table 1. The VLBI celestial frames used; A1, A2, A3 are rotation angles from an individual frame to the compiled one. N is the number of RS. Unit: 0.001".

Catalog	N	A1	A2	A3
RSC(GSFC) 93 R 05	449	+3.08±0.02	+0.96±0.02	-1.87±0.01
RSC(JPL) 92 R 02	333	-0.76±0.02	+0.42±0.02	+0.51±0.02
RSC(NOAA) 93 R 02	107	+0.11±0.02	+0.05±0.02	+0.03±0.02
RSC(USNO) 93 R 09	125	+0.77±0.03	+0.19±0.03	+0.05±0.03
RSC(GIUB) 93 R 01	43	+0.10±0.07	+2.44±0.08	-0.11±0.06

At the first stage we have compiled the catalogue of 39 primary radio sources which are common for RSC(GSFC) 93 R 05, RSC(JPL) 92 R 02, RSC(NOAA) 93 R 02 and RSC(IERS) 90 C 01. For this purpose internal accuracy of individual catalogues was analysed and their weights, given in Table 2, were derived according to the method proposed by the authors (Kuryanova and Yatskiv, 1992).

Table 2. Normalized weights of individual catalogs.

Catalog	Weight
RSC(GSFC)	0.226
RSC(JPL)	0.157
RSC(NOAA)	0.617

For the initial orientation of the frame RSC(GAOUA) 94 C 01, the orientation of the frame RSC(IERS) 90 C 01 was used. At the second stage the system of primary RS was extended to other sources (secondary and complementary) in catalogues under consideration. The catalogue contains 504 radio sources. The relative orientations and RMS differences of catalogue RSC(GAOUA) 94 C 01 and compiled catalogues constructed by IERS (IERS A.R.) are shown in Table 3 and Table 4.

Table 3. Relative orientation and RMS differences of RSC(GAOUA) 94 C 01 and other compiled catalogs determined from primary RS. Unit: 0.001".

Catalog	N	A1	A2	A3	$D\alpha\cos\delta$	$D\delta$
RSC(IERS) 90 C 01	37	+0.03	-0.02	-0.00	±0.218	±0.245
RSC(IERS) 91 C 01	32	-0.04	-0.10	-0.02	±0.263	±0.431
RSC(IERS) 92 C 01	39	-0.02	-0.23	-0.10	±0.220	±0.218
RSC(IERS) 93 C 01	39	+0.09	-0.08	-0.15	±0.144	±0.009

Table 4. Relative orientation and RMS differences of RSC(GAOUA) 94 C 01 and RSC(IERS) 93 C 01 determined from primary RS selected by IERS. Unit: 0.001".

Catalog	N	A1	A2	A3	Dαcosδ	Dδ
RSC(IERS) 93 C 01	166	+0.12	-0.07	-0.13	±0.123	±0.117

The average values of internal accuracy of this catalogue is given in Table 5.

Table 5. Internal accuracy of positions of RS in RSC(GAOUA) 93 C 01. N is number of RS. Unit: 0.001".

RS	Designation	N	Sαcosδ	Sδ
Primary	P,P1	166	±0.14	±0.16
Secondary	S	135	±0.38	±0.40
Complementary	C	203	±5.49	±2.22

Catalogue RSC(GAOUA) 94 C 01 is available on request from the Main Astronomical Observatory of Academy of Sciences of Ukraine.

References

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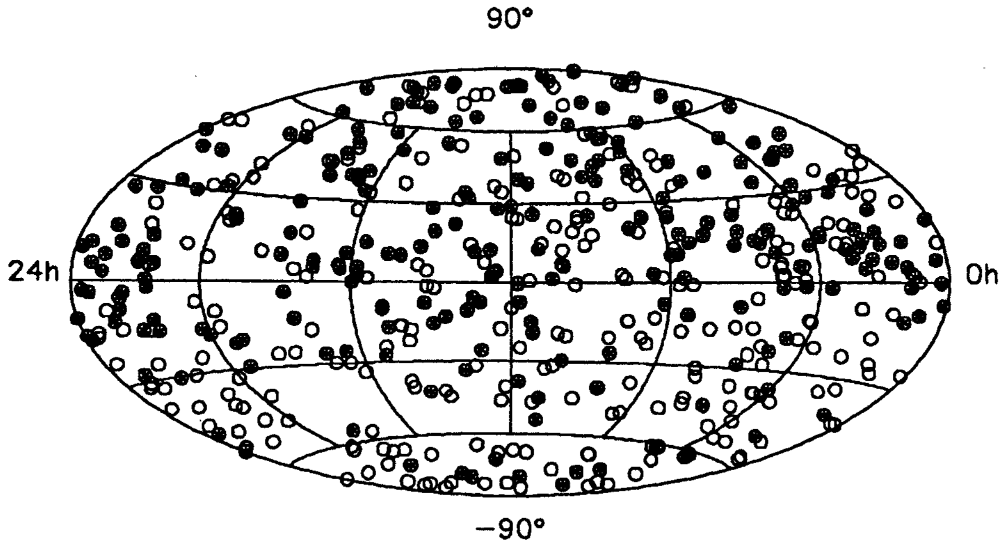
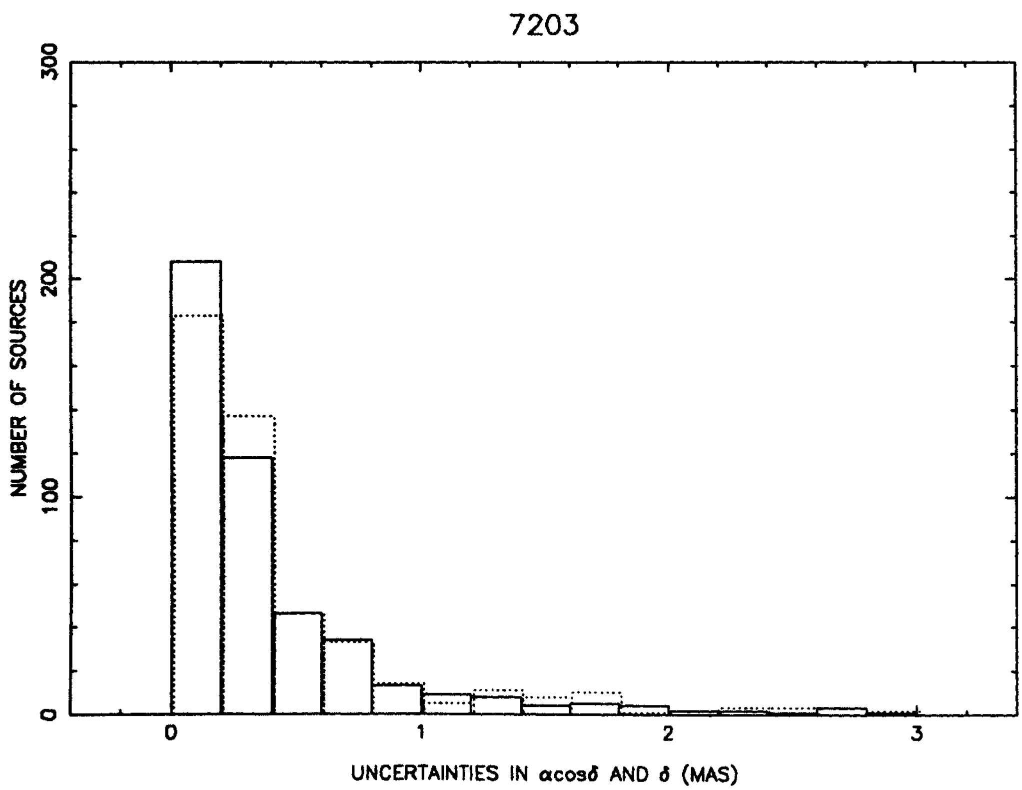


Distribution over the sky of the 505 extragalactic radio sources of the celestial frame RSC(GAOUA) 94 C 01. Filled circles indicate radio sources with uncertainties in right ascension ($\alpha \cos \delta$) and declination smaller than 0.0003".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(GAOUA) 94 C 01. 47 radio sources with uncertainties larger than 0.003" are not shown.

A COMBINATION OF EARTH ORIENTATION DATA: SPACE93

JPL 94 C 01

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A combination of independently-determined Earth orientation data has been generated from space-geodetic observations spanning 1976-1993. The approach taken is based upon a Kalman filter that was developed at the Jet Propulsion Laboratory (JPL) for just such a purpose (Eubanks 1988; Morabito *et al.* 1988). The Kalman filter is a sequential estimation technique that combines observations of the Earth's orientation in a rigorously self-consistent manner producing smoothed, interpolated estimates of UT1 and the x- and y-components of polar motion (PMX and PMY, respectively). Information about the data that have been combined is given in Table 1. All publicly available, independent determinations of the Earth's orientation by the modern, space-geodetic techniques of very long baseline interferometry (VLBI), satellite laser ranging (SLR), lunar laser ranging (LLR), and the global positioning system (GPS) have been used. Since it was desirable to combine only independent determinations of the Earth's orientation, only one LLR data set was used, namely, that determined at JPL (Newhall *et al.*, 1993), and only one SLR data set was used, namely, that determined at the University of Texas Center for Space Research (UTCSR; Eanes and Watkins, 1993). Note that the SLR UT1 results were not used in generating SPACE93 due to problems associated with separating this component of the Earth's orientation from the effects of unmodeled forces acting on the satellite causing the node of its orbit to drift. Two different data sets derived from GPS measurements were used: (1) that determined at the Scripps Institution of Oceanography from daily measurements spanning August 25, 1991 to June 20, 1992 (Bock *et al.*, 1993); and (2) that determined at the Jet Propulsion Laboratory from daily measurements spanning June 21, 1992 to January 9, 1994 (Zumberge *et al.*, 1993). Note that in both cases only the polar motion results determined from the GPS measurements were used in generating SPACE93. Three different data sets derived from independent VLBI measurements were used: (1) the approximately twice-a-week single baseline measurements made using the radio telescopes of NASA's Deep Space Network (DSN; Steppe *et al.*, 1993); (2) the measurements made under the auspices of the International Radio Interferometric Surveying (IRIS) subcommission and analyzed at NOAA's Laboratory for Geosciences (IRIS Earth Orientation Bulletin No. 120, February, 1994; note that for reasons given below only the IRIS Intensive UT1 results were used); and (3) the UTPM determinations made by the VLBI group of the NASA Crustal Dynamics Project (CDP) at Goddard Space Flight Center (GSFC) from both their own CDP VLBI measurements and from their reduction of the IRIS and United States Naval Observatory (USNO) multibaseline measurements (Ma, private communication, 1993). Since the CDP data set used here includes UTPM values determined from the multibaseline measurements taken by both IRIS and the USNO, no separate IRIS multibaseline or USNO data sets were used in generating SPACE93.

Table 1. Data combined

DATA SET NAME	DATA TYPE	ANALYSIS CENTER	DATA SPAN	NUMBER POINTS
LLR (JPL93M01; VAR LAT, UT0)				
McDonald Cluster	LLR	JPL	22MAY76-14JAN93	390
CERGA	LLR	JPL	07APR84-14FEB93	373
Haleakala	LLR	JPL	10FEB85-11AUG90	68
UTCSR (CSR93L01; PMX, PMY)				
LAGEOS	SLR	UTCSR	19MAY76-04FEB93	1797
DSN (JPL93R01; T, V)				
CA-Spain Cluster	VLBI	JPL	26NOV79-08JAN94	489
CA-Australia Cluster	VLBI	JPL	28OCT78-05JAN94	495
CDP (GLB922)				
Multibaseline	VLBI	GSFC	04AUG79-29DEC93	1550
Westford-Ft. Davis	VLBI	GSFC	25JUN81-01JAN84	103
Westford-Mojave	VLBI	GSFC	21MAR85-06AUG90	18
IRIS (UT1MC19JAN94; UT1)				
Intensive	VLBI	NOAA	02APR84-09JAN94	2153
....				
GPS (SIO93P01; PMX, PMY)				
Scripps	GPS	SIO	25AUG91-20JUN92	286
GPS (JPL92P02; PMX, PMY)				
JPL FLINN Analysis	GPS	JPL	21JUN92-09JAN94	521

Before combining the series, the effect of the solid Earth tides upon UT1 was removed by using the model of Yoder *et al.* (1981). Also, the model of Dickman (1993) was used to remove the effect upon UT1 of the ocean tides at the Mf, Mf', Mm, and Ssa tidal frequencies [the Dickman (1993) oceanic corrections to the Yoder *et al.* (1981) results were actually removed]. Finally, the empirical model of Herring (1992) was used to remove the effect of the semi-diurnal and diurnal ocean tides from the IRIS Intensive UT1 values since these tidal terms had been added back and were included in the released IRIS Intensive UT1 values. No subdaily ocean tidal terms were removed from any of the other series used in generating SPACE93 since none of the other series listed in Table 1 had these terms added back to them (the particular CDP series used in generating SPACE93 was a special solution in which the subdaily tidal terms had not been added back and were therefore not included in the final UTPM values; Ma, private communication, 1993).

Prior to combining the data, series-specific corrections were applied for bias and rate, and the stated uncertainties were adjusted by multiplying them by series-specific scale factors. Values for these bias-rate corrections and uncertainty scale factors were determined in an iterative, round-robin type approach wherein each data set was compared to a combination of all other data sets (except for the two GPS series which were treated separately as described below). First, a reference series (SPACE92; Gross, 1993) was used to initially correct the bias and rate of each individual series so that it agrees (in bias and rate) with the reference series. This was done for the sole purpose of initially aligning the series with each other in an attempt to reduce the required number of round-robin iterations. The stated uncertainties of the series were not adjusted at this time. Any inconsistencies introduced by using a reference series for this initial bias-rate alignment should be removed during the subsequent iterative, round-robin procedure.

After initial bias-rate alignment, the round-robin procedure was performed wherein the bias and rate of each individual series was iteratively adjusted so as to be in agreement with the bias and rate exhibited by a combination of all the other series, with rate adjustments being determined only for those series whose overlap with all the other series was great enough that reliable rate determinations could be made. The stated uncertainty of each series was adjusted by applying a multiplicative factor that made the residual of that data, when differenced with a combination of all other data, have a reduced chi-square of one. Note that the formal error associated with the residual in calculating the reduced chi-square accounts for the error of interpolation between the time of the residual and the times of other data points by using the stochastic model of the UTPM process contained in the Kalman filter. The incremental bias-rate corrections and uncertainty scale factors thus determined for each of the individual series were then applied to the series and the process repeated until convergence was achieved (convergence being indicated by the incremental bias-rate corrections approaching zero, and the incremental uncertainty scale factors approaching one). At the completion of this iterative, round-robin process, relative bias-rate corrections will have been determined that make the data sets agree with each other in bias and rate, and uncertainty scale factors will have been determined that make the residual of each data set (when differenced with a combination of all others) have a reduced chi-square of one.

When performing this iterative, round-robin procedure to determine bias-rate corrections and uncertainty scale factors, each data type is analyzed (and results reported) in the natural reference frame for that data type. For single baseline VLBI measurements this is the transverse (T), vertical (V) frame (Eubanks and Steppe 1988); for single station LLR measurements this is the variation of latitude (LAT), UT0 frame; and for GPS, SLR and multibaseline VLBI measurements this is the usual UTPM (PMX, PMY, UT1) frame.

For the purpose of determining bias-rate corrections and uncertainty scale factors, the LLR observing stations at McDonald were clustered, so that a common bias-rate correction and uncertainty scale factor was determined for all the McDonald LLR series. This was done so that rate adjustments could be made to these series.

There is not enough overlap with the other, independent Earth orientation series to allow a reliable rate correction to be determined for any individual McDonald station-derived LLR series. Thus, without clustering the McDonald stations, it would only be possible to make bias corrections to the McDonald LLR series, with consequent deleterious effects on the rate of the UT1 values prior to about 1982 in the final, combined series. Similarly, the individual DSN radio telescopes in California were clustered, as were those in Spain and, separately, in Australia, so that a common bias-rate correction and uncertainty scale factor was determined for all the California-Spain single baseline Earth orientation series, as well as for all the California-Australia series.

During the iterative, round-robin procedure, outlying data points were deleted. Before deleting any data points, a few round-robin iterations were completed in order to converge on initial values for the uncertainty scale factors. During subsequent iterations, those data points within a given series were deleted whose residual values were greater than three times their adjusted uncertainties, where the residual values were those resulting from fitting a bias and rate to the difference of that series with a combination of all other series. During the final round-robin iteration, no series contained data points whose residual values were greater than three sigma. A total of 167 data points, or about two percent of the available data points, were thus deleted from all the series.

Bias corrections and uncertainty scale factors were determined for each of the two GPS series by separately comparing them to a combination of all other, independent series after the other series had had the bias-rate corrections and uncertainty scale factors applied to them that had been previously determined for them as described above. Only bias corrections were determined and applied to the GPS series since their individual overlap with the other, independent series was not great enough to allow reliable rate corrections to be determined. During this comparison, outlying data points (i.e., those whose residual values were greater than three times their adjusted uncertainties) were also deleted.

Finally, each data set was placed within an IERS reference frame by applying to it an additional bias-rate correction that is common to all the data sets. This additional correction was determined by first combining all the data (including the two GPS series, and after applying to all the data the relative bias-rate corrections and uncertainty scale factors determined above). This intermediate combination was then compared to the IERS combination EOP(IERS) 90 C 04 (e.g., 1992 IERS Annual Report) for the years 1984-1993 in order to obtain the additional bias-rate correction required to make it (and therefore each individual data set) agree in bias and rate with the IERS combination. This additional bias-rate correction was then applied to each data set along with the relative bias-rate corrections in order to make the data sets agree with each other and be in that IERS reference frame defined by the Earth orientation series EOP(IERS) 90 C 04.

The total bias-rate correction (the sum of the relative and IERS corrections) that has been determined for each data set is given in Table 2. Except for the two GPS series (see below), the values for the bias-rate corrections given in Table 2 are the sum of all the incremental corrections, the corrections applied to initially align the series with each other, and the additional, common correction applied in order to place each series within the IERS reference frame. The values for the uncertainty scale factors given in Table 2 are the products of all the incremental scale factors determined during the iterative, round-robin procedure. The errors in the bias-rate corrections (given in parentheses in Table 2) are the formal errors in the determination of the incremental bias-rate corrections during the last iteration of the iterative, round-robin procedure. There are no bias-rate entries in Table 2 for components that were either not used (e.g., the SLR UT1 component), or not available (e.g., the IRIS Intensive PMX and PMY components). Note that the same IERS rate correction is applied to all the data sets, including those (such as the GPS series) for which no relative rate correction could be determined. Therefore, the rate correction given in Table 2 for those data sets for which no relative rate correction could be determined is simply the IERS rate correction, but given, of course, in the natural reference frame for that data set. In these cases, no errors for the rate corrections are given.

Since the GPS series were not included in the iterative, round-robin procedure, the bias-rate corrections given in Table 2 for them are just the sum of the relative corrections that were separately determined for them (see above) and the additional, common correction needed to place them within the IERS reference frame. The errors in the bias corrections given in Table 2 for the GPS series (shown in parentheses in Table 2) are the formal errors in determining the relative corrections. The uncertainty scale factors given in Table 2 for the GPS series are just the scale factors determined for them as described above when separately comparing them to combinations of all the other, independent series.

Note that the entries in Table 2 should not be used as a measure of the relative accuracy of the Earth orientation series. No attempt was made to place the series within a common reference frame prior to determining bias-rate corrections for them. Thus, the values for the bias-rate corrections given in Table 2 include the effects upon the Earth orientation series of reference frame differences.

The final UTPM combination was generated by combining all of the data (including the GPS results) after adjusting their biases, rates, and uncertainties by the amounts given in Table 2. This final combination, spanning May 20.0, 1976 to January 9.0, 1994, is designated SPACE93 and is given as daily values at midnight of PMX, PMY, UT1-UTC, their formal errors (1 sigma), and correlations. The model of Yoder et al. (1981) was used to add back the effect of the solid Earth tides upon UT1 (the full amplitude of the tidal effect at the epoch of the time tag was added back). Similarly, the model of Dickman (1993) was used to add back the ocean tidal corrections to the Yoder *et al.* (1981) model values at the Mf, Mf', Mm, and Ssa tidal frequencies. However, no diurnal or semi-diurnal ocean tidal terms were added back. The three correlations given at each time tag are the correlations between the UTPM values at that time tag. Improvements to the observing systems (both in the hardware and software, and in the number of systems) have led to more precise determinations of the Earth's orientation. This improvement is reflected in SPACE93 by the reduction of the UTPM formal errors from about 2 mas in polar motion and 0.5 ms in UT1 during the late 1970's to their current values of about 0.2 mas in polar motion and 0.02 ms in UT1.

Table 2. Adjustments to data sets

DATA SET NAME	BIAS (mas)			RATE (mas/yr)			UNCERTAINTY SCALE FACTOR		
LLR (JPL93M01)	LAT	UT0		LAT	UT0		LAT	UT0	
McDonald Cluster	1.270	1.703		-0.676	-0.225		1.012	1.301	
	(0.350)	(0.327)		(0.079)	(0.086)				
CERGA	-0.289	1.635		0.075	-0.174		1.571	1.255	
	(0.211)	(0.118)		(0.058)	(0.036)				
Haleakala	1.346	1.042		-0.219	-0.214		1.207	1.330	
	(0.331)	(0.253)		(0.219)	(0.175)				
DSN (JPL93R01)	T	V		T	V		T	V	
CA-Spain Cluster	0.626	-1.067		-0.038	-0.184		1.427	1.209	
	(0.077)	(0.180)		(0.019)	(0.045)				
CA-Australia Cluster	-0.561	1.600		-0.192	0.076		1.472	1.242	
	(0.053)	(0.155)		(0.014)	(0.040)				
CDP (GLB922)	T	V		T	V		T	V	
Westford-Ft. Davis	2.746	-2.589		0.587	-0.192		0.659	0.811	
	(1.912)	(3.285)		(0.386)	(0.656)				
Westford-Mojave	-0.659	-1.094		0.007	-0.016		3.048	0.941	
	(0.214)	(0.385)							
CDP (GLB922)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
Multi	0.155	-1.739	-1.617	-0.129	-0.049	-0.057	2.067	2.051	2.133
	(0.028)	(0.025)	(0.032)	(0.008)	(0.007)	(0.009)			
UTCSR (93L01)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
LAGEOS	0.021	0.030	---	-0.032	-0.162	---	0.747	0.680	---
	(0.024)	(0.021)		(0.009)	(0.008)				
IRIS (19JAN94)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
Intensive	---	---	1.907	---	---	0.012	---	---	1.345
			(0.027)			(0.008)			

DATA SET NAME	BIAS (mas)			RATE (mas/yr)			UNCERTAINTY SCALE FACTOR		
GPS (SIO93P01)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
Scripps	-1.003	-1.736	---	0.017	0.026	---	2.141	1.968	---
	(0.036)	(0.038)							
GPS (JPL92P02)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
JPL FLINN	-0.717	-1.578	---	0.017	0.026	---	4.023	2.719	---
	(0.028)	(0.021)							

Reference date for rate adjustment is 1988.0

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EOP(JPL) 94 C 01 From May 1976 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
1976	223	5.08	223	4.10	223	7.32
1977	365	3.48	365	2.78	365	4.81
1978	365	3.63	365	2.55	365	5.83
1979	365	3.05	365	2.36	365	4.37
1980	366	1.58	366	1.03	366	2.87
1981	365	1.33	365	1.02	365	1.86
1982	365	1.00	365	0.85	365	1.24
1983	365	0.87	365	0.82	365	0.96
1984	366	0.50	366	0.44	366	0.52
1985	365	0.42	365	0.37	365	0.33
1986	365	0.37	365	0.33	365	0.29
1987	365	0.30	365	0.27	365	0.28
1988	366	0.26	366	0.24	366	0.25
1989	365	0.25	365	0.23	365	0.22
1990	365	0.22	365	0.21	365	0.19
1991	365	0.21	365	0.20	365	0.19
1992	366	0.17	366	0.16	366	0.16
1993	365	0.20	365	0.17	365	0.20
1994	9	0.21	9	0.17	9	0.51

COMBINATION OF PRECISE OBSERVATIONS OF THE ORIENTATION OF THE EARTH

NEOS 94 C 01

[The procedure for obtaining this series is described in the IERS Annual Report for 1993, part. III].

EOP(NEOS) 94 C 01 From Jun 1979 to Feb 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
1979	185	1.81	185	2.56	185	2.71	0		0	
1980	366	1.91	366	1.10	366	1.79	96	1.98	96	0.87
1981	365	1.87	365	1.49	365	2.71	365	1.98	365	0.87
1982	365	1.71	365	1.72	365	1.84	365	1.98	365	0.87
1983	365	1.67	365	1.28	365	1.94	365	1.98	365	0.87
1984	366	0.94	366	0.79	366	1.18	366	0.79	366	0.30
1985	365	0.62	365	0.58	365	0.84	365	0.74	365	0.29
1986	365	0.52	365	0.56	365	0.69	365	0.67	365	0.27
1987	365	0.58	365	0.59	365	0.88	365	0.69	365	0.30
1988	366	0.45	366	0.43	366	0.79	366	0.67	366	0.25
1989	365	0.40	365	0.43	365	0.51	365	0.62	365	0.30
1990	365	0.51	365	0.51	365	0.58	365	0.59	365	0.24
1991	365	0.40	365	0.46	365	0.40	365	0.65	365	0.30
1992	366	0.18	366	0.45	366	0.33	366	0.54	366	0.26
1993	365	0.08	365	0.54	365	0.39	365	0.57	365	0.28
1994	47	0.12	47	0.12	47	0.54	47	0.30	47	0.15

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).

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AAM(JMA) 87 * 01 From 1983 to 1993

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

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 1993. 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.

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)

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.

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 1993 IERS Annual Report.

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AAM(NMC) 87 * 01 From 1976 to 1993

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

EFFECTIVE ATMOSPHERIC ANGULAR MOMENTUM FUNCTIONS CALCULATED AT THE U.K. METEOROLOGICAL OFFICE AAM(UKMO) 83 *01

Throughout 1993, 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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Quarterly report on numerical products from Bracknell - U.K. Meteorological Office, London.

AAM(UKMO) 83 * 01 From 1983 to 1993

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

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