# IERS TECHNICAL NOTE 11

## Earth orientation reference frames and atmospheric excitation functions submitted for the 1991 IERS Annual Report

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

P. Charlot (ed.)

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Central Bureau of IERS - Observatoire de Paris
61, avenue de l'Observatoire
F-75014 PARIS - France

# IERS Technical Notes

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

**Back issues**

No 1 : C. Boucher and Z. Altamimi. The initial IERS Terrestrial Reference Frame.

No 2 : Earth orientation and reference frame determinations, atmospheric excitation functions, up to 1988 (Annex to the IERS Annual Report for 1988). *[No longer available, superseded by T.N. No 5].*

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 5: Earth orientation and reference frame determinations, atmospheric excitation functions, up to 1989 (Annex to the IERS Annual Report for 1989). *[Superseded by T.N. No 8].*

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 8: Earth orientation and reference frame determinations, atmospheric excitation functions, up to 1990 (Annex to the IERS Annual Report for 1990).

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 11: P. Charlot (ed.). Earth orientation, reference frames and atmospheric excitation functions submitted for the 1991 IERS Annual Report.

**Future issues**

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

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

# VERY LONG BASELINE INTERFEROMETRY

# EARTH ORIENTATION PARAMETERS FROM IRIS-S VLBI MEASUREMENTS

GIUB 92 R 01
GIUB 92 R 02

A. Nothnagel, J. Campbell, Geodetic Institute of the University of Bonn, Fed. Rep. of Germany
G.D. Nicolson, Hartebeesthoek Radio Astronomy Observatory, South Africa

In 1991 the VLBI group at the Geodetic Institute of the University of Bonn (GIUB) regularly correlated and analysed VLBI experiments which are observed once per month under the acronym IRIS-S (International Radio Interferometric Surveying - South). The standard configuration of the IRIS-S network consists of five stations, *i.e.* Westford Observatory (Massachusetts, USA), Richmond Observatory (Florida, USA), Mojave Base Station (California, USA), Wettzell Geodetic Fundamental Station (Bavaria, Federal Republic of Germany) and Hartebeesthoek Radio Astronomy Observatory (South Africa).

The data analysed consists of 12 sessions in monthly intervals. Two different terrestrial and celestial reference frames were used in two separate analyses. The first set of reference frames was taken from the results of the global VLBI solution GLB722 (= GSFC 91 R 04) of the VLBI group at the NASA Goddard Space Flight Center which contains all Mark III S/X experiments from 1979 to December 1990. The list of station positions of GLB722 included continental drift parameters dx/dt, dy/dt, dz/dt for each station which permitted the computation of station coordinates refered to selected epochs. For the second set of computations the celestial reference frame RSC(IERS) 91 C 01 and the IERS Terrestrial Reference Frame 1990 (ITRF 90) for epoch 1988.0 together with the AM0-2 continental drift model (Minster and Jordan, 1978) were used.

All sessions of the IRIS-S campaign were individually reduced using the CALC 7.2/SOLVE software system (Ryan, 1990) which is based on the IERS 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 were calculated according to the Shapiro model (Ryan, 1990) and Hellings (1987) correction for relativistic bending. Horizontal and vertical ocean loading displacement effects of Scherneck (1991) were applied to the delay observables. For the tropospheric corrections we used the CfA model (Davis *et al.*, 1985) based on surface meteorological data. The ionospheric refraction is dispersive and was calibrated by dual frequency observations. Only delay observables were used in our analyses.

In the least squares adjustments the two polar motion components xp, yp, Universal time UT1-TAI and two nutation offsets relative to the IAU 1980 Theory of Nutation (Wahr, 1981) were estimated as principal parameters. In addition, relative offsets, rates and higher order terms of the atomic clocks as well as atmospheric excess path delays in zenith direction and their rates had to be estimated. In order to best model the behaviour of the atmosphere at each station additional rate changes were introduced at epochs where the atmospheric situation as reflected by the surface weather data, *i.e.* temperature, pressure and relative humidity, changed significantly. Extra parameters for modeling the station clock behaviour were chosen depending on obvious deviations in the residuals.

The formal errors of the pole coordinates were based on observation weights adjusted so that the Chi-square per degree of freedom ratio was close to unity (p=observation weights, v=post fit residuals, n=number of observations, u=number of unknown parameters). These contributions to the a priori variances should account for unmodelled effects in the data reduction (Herring *et al.*, 1986).

The results of the IRIS-S analyses for the period of January 1991 to December 1991 are listed below.

## References

Davis *et al.*, 1985: *Radio Science*, **20**, 1593.
Hellings, R.W., 1986: *Astron. J.*, **91**, 1446.
Herring *et al.*, 1986: *J. Geophys. Res.*, **91**, No. B8, 8341.
Kaplan, G.H., 1981: USNO *Circular No. 163*, Washington D.C.
Ma *et al.*, 1990: *IERS Technical Note 5*, Observatoire de Paris.
McCarthy (ed.) *et al.*, 1989: *IERS Technical Note 3*, Observatoire de Paris.
Minster, J.B., Jordan, T.H., 1978: *J. Geophys. Res.*, **83**, 5331 - 5354.
Ryan, J.W., 1989: *CALC-7 Release Document*, GSFC.
Scherneck, H.G., 1991: *Geophys. J. Int.*, **106**, 677 - 694.

EOP(GIUB) 92 R 01 From Jan 1991 to Dec 1991

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 |
| 1991 | 12 | 0.18 | 12 | 0.13 | 12 | 0.10 | 12 | 0.23 | 12 | 0.11 |

EOP(GIUB) 92 R 02 From Jan 1991 to Dec 1991

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 |
| 1991 | 12 | 0.21 | 12 | 0.14 | 12 | 0.12 | 12 | 0.27 | 12 | 0.13 |

# EARTH ORIENTATION PARAMETERS, SITE POSITIONS WITH ESTIMATED SITE VELOCITIES, AND SOURCE POSITIONS FROM THE NASA CRUSTAL DYNAMICS PROJECT USING AM0-2 AND UNIFORM VELOCITY FOR HRAS 085: SOLUTION GLB831

GSFC 92 R 01

C. Ma, Code 921, Goddard Space Flight Center, Greenbelt, Md. 20771, USA,
D. S. Caprette, Hughes STX, 4400 Forbes Blvd., Lanham, Md. 20706, USA,
J. W. Ryan, Code 926, Goddard Space Flight Center, Greenbelt, Md. 20771, USA

Mark III VLBI data acquired since 1979 by the NASA Crustal Dynamics Project, POLARIS/IRIS, the Geographical Survey Institute (Japan), the USNO Navnet, and the US Naval Research Laboratory celestial reference frame program have been analyzed for Earth orientation parameters, the terrestrial reference frame and the celestial reference frame. The terrestrial reference frame origin is set to be near the ITRF90 origin and is defined by the a priori position of the 18-m Westford antenna on 1988 Jan. 1. The orientation of the frames is defined by values from the USNO one-day concrete EOP series and the standard J2000.0 precession and IAU 1980 nutation models for the reference date 1986 Nov. 5 and by the position of WESTFORD and the direction of the WESTFORD-RICHMOND baseline, which evolve according to the AM0-2 model. The right ascension origin is defined by the a priori position of 0420-014.

Short period tidal terms in UT1 have not been removed from the tabulated values of UT1-UTC. Since the solution contains all geodetic (both large and small network) and astrometric sessions, editing criteria based on the quality of the results (uncertainties and correlations) should be applied before using the EOP tables.

The 3-dimensional velocities of all sites with sufficient data were estimated except for RICHMOND, KAUAI, and MATERA. Apart from the motion of the AM0-2 model, the position of RICHMOND was constrained to change only in the a priori direction of WESTFORD. The vertical rate of KAUAI was constrained to be zero to provide a more robust geometry. The data for MATERA were weaker than the normal criteria for velocity estimates, but the horizontal components were nonetheless estimated because they appeared to be large and geophysically plausible. The positions of six sites (YAKATAGA, SOURDOGH, FORTORDS, KODIAK, WHTHORSE, and PRESIDIO) each had one discontinuous change in position related to seismic events. The position of the site following the seismic event, propagated before and after the event, is marked with "ep" in the site position tables. Also, the assumed Gregorian date of the event appears to the right of the last data field. The velocities of several sets of sites (FORT ORD-FORTORDS, KASHIMA-KASHIM34, KAUAI-HALEAKAL, MOJAVE12-MOJ 7288-DSS15, OVRO 130-OVR 7853, SESHAN25-SHANGHAI) 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.

~100 sources used in the geodetic programs form the core of the celestial reference frame. ~250 sources have formal errors under 1 mas. The remaining sources include a number that have very weak data. Both delay and delay rate data were used for astrometric and source survey sessions.

All uncertainties are 1-sigma formal standard errors from the sequential least-squares solution GLB831 described below.

The basic models used to calculate the VLBI delays are consistent with the IERS standards and are contained in the Goddard CALC 7.4 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, CfA 2.2 dry troposphere mapping, DE200 solar system ephemeris, and a modified Hellings (1986) VLBI time delay consistent with the alternative IERS standard model at 1 ps rms. The a priori pole position for each observation was interpolated linearly from the one-day USNO concrete series. The a priori UT1 value for each observation was derived from the one-day USNO concrete series by first removing the IERS standard tidal model, interpolating linearly to the epoch of observation, then restoring the standard tidal model. 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 dry troposphere was modeled from local meteorological data and the residual wet troposphere was estimated using a continuous piecewise-linear function with the wet Chao model. 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. The provisions for episodic motion and for linking site velocities are the major changes from our previous submissions.

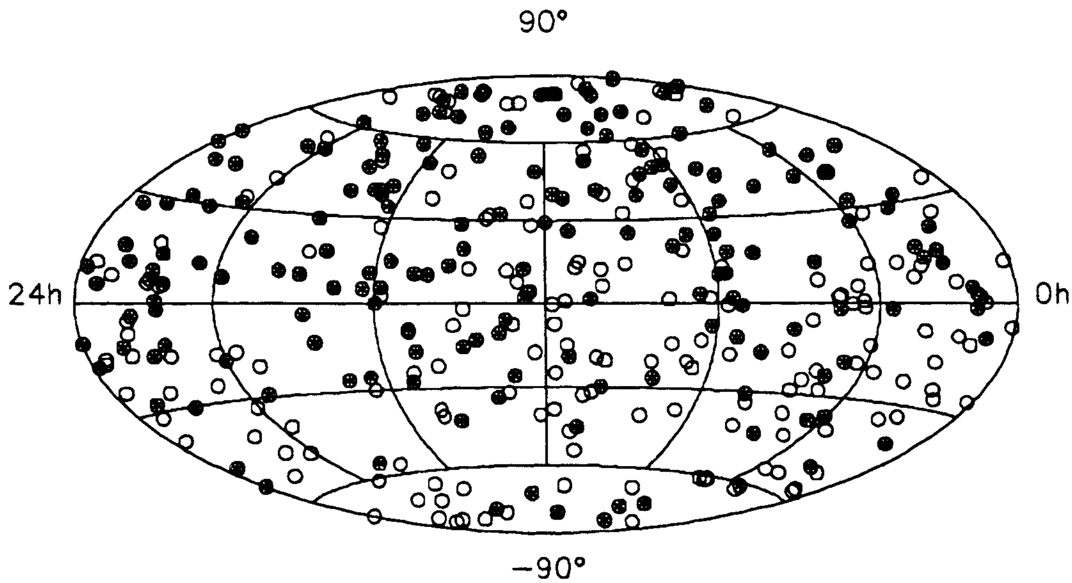
843523 dual-frequency Mark III delays and 23726 delay rates from 1677 sessions using fixed stations and mobile sites were combined to estimate site positions and velocities, source positions, Earth orientation parameters, and troposphere and clock behavior from a least-squares solution with 1309 global parameters and 328302 arc parameters. There were 664665.5 degrees of freedom. A weak input covariance on polar motion and UT1 (X,Y - 45 mas, UT1 - 3 ms) was used so that all three components could be estimated for each session with more reliable indication of uncertainty and correlation. The weighted rms post-fit residual of the solution was 42.5 ps for delays and 79.7 fs/s for rates. The reduced chi-square was 1.01 including the constraints for the wet troposphere, clocks, and EOP in the computation of the degrees of freedom (Theil, 1963).

The complete Earth orientation time series is designated EOP(GSFC)92 R 01. Other results are source positions designated RSC(GSFC)92 R 01 and site coordinates at 1979-92 Jan 1.5 designated SSC(GSFC)92 R 01.

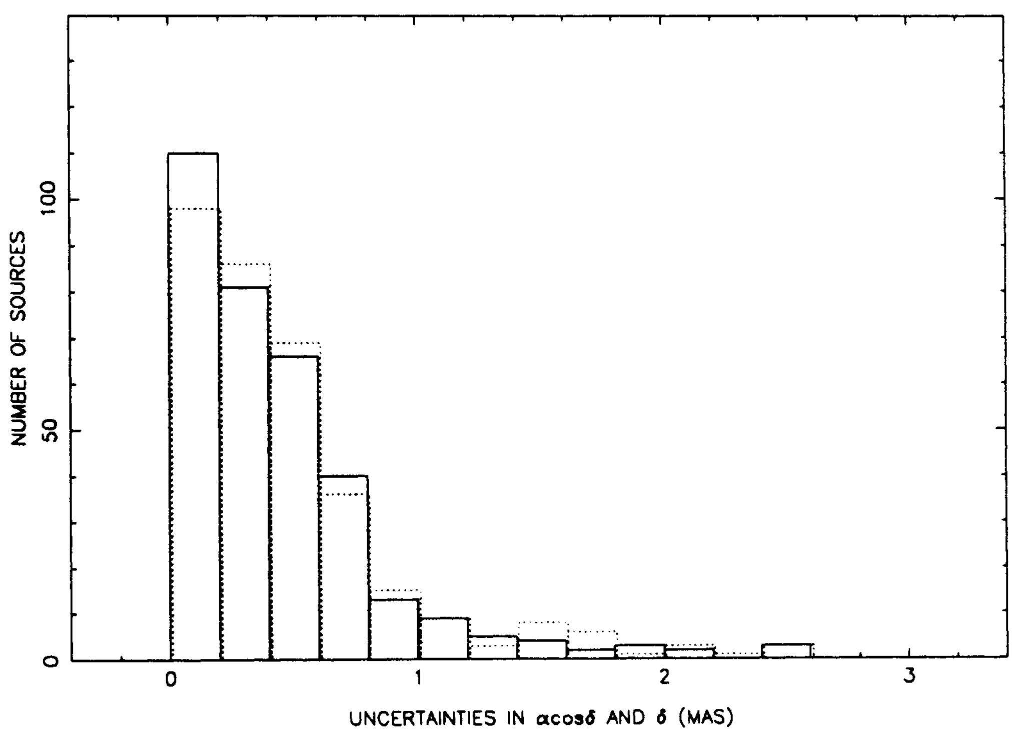
## References

Hellings, R. W., 1986: *Astron. J.*, **91**, 1446.
Theil, H., 1963: *Amer. Stat. Ass. J.*, **58**, 401.

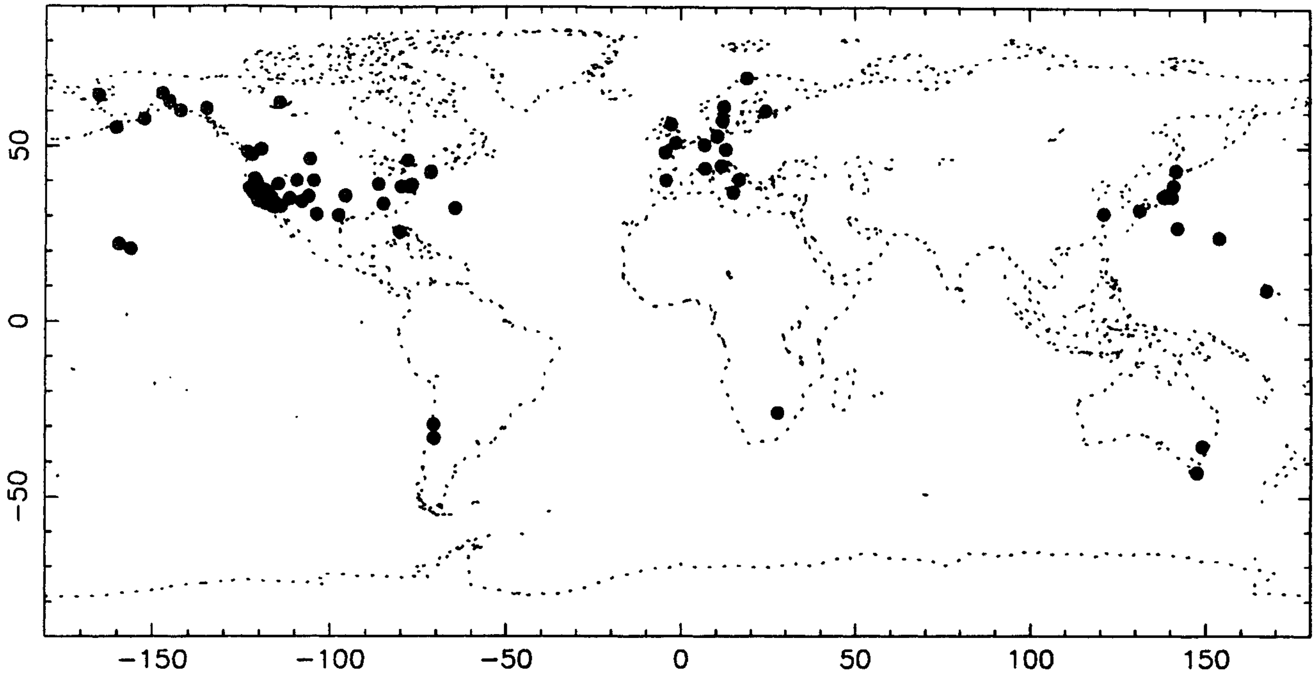
SUMMARY DESCRIPTION FOR SOLUTION GSFC 92 R 01: SEE P. 15



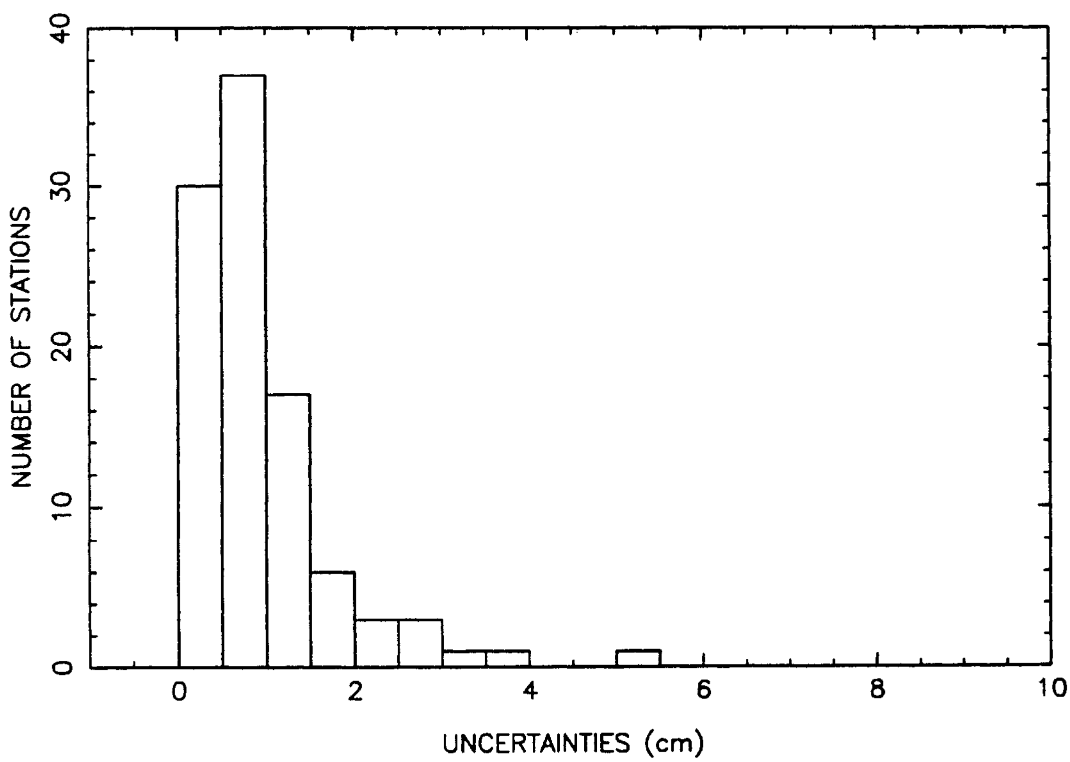

Distribution over the sky of the 357 extragalactic radio sources of the celestial frame RSC(GSFC) 92 R 01. Circles with asterisks indicate radio sources with uncertainties in right ascension ($\alpha\cos\delta$) and declination smaller than 0.0005".




Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(GSFC) 92 R 01. 19 radio sources with uncertainties larger than 0.003" are not shown.




Distribution of the 82 sites of the terrestrial frame SSC(GSFC) 92 R 01.




Distribution of the uncertainties (quadratic mean of $\sigma_X$, $\sigma_Y$, $\sigma_Z$) for the 100 stations of the terrestrial frame SSC(GSFC) 92 R 01. 1 station with uncertainty larger than 10 cm is not shown.

EOP(GSFC) 92 R 01 From Aug 1979 to Dec 1991

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

| YEAR | X | | Y | | UT1 | | δψ | | δε | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Nb | Sigma | Nb | Sigma | Nb | Sigma | Nb | Sigma | Nb | Sigma |
| 1979 | 2 | 1.25 | 2 | 2.50 | 2 | 0.88 | 2 | 1.72 | 2 | 0.62 |
| 1980 | 8 | 0.85 | 8 | 0.71 | 8 | 0.37 | 8 | 1.28 | 8 | 0.38 |
| 1981 | 25 | 12.73 | 25 | 40.48 | 25 | 10.32 | 25 | 2.53 | 25 | 0.88 |
| 1982 | 43 | 12.76 | 43 | 40.48 | 43 | 10.34 | 43 | 2.63 | 43 | 0.93 |
| 1983 | 53 | 12.65 | 53 | 40.46 | 53 | 10.25 | 53 | 2.02 | 53 | 0.69 |
| 1984 | 86 | 0.72 | 86 | 0.68 | 86 | 0.35 | 86 | 1.00 | 86 | 0.37 |
| 1985 | 91 | 0.49 | 91 | 0.48 | 91 | 0.24 | 91 | 0.70 | 91 | 0.26 |
| 1986 | 109 | 0.48 | 109 | 0.43 | 109 | 0.23 | 109 | 0.69 | 109 | 0.26 |
| 1987 | 130 | 0.45 | 130 | 0.42 | 130 | 0.22 | 130 | 0.64 | 130 | 0.24 |
| 1988 | 124 | 0.36 | 124 | 0.34 | 124 | 0.17 | 124 | 0.53 | 124 | 0.21 |
| 1989 | 148 | 0.30 | 148 | 0.29 | 148 | 0.14 | 148 | 0.48 | 148 | 0.20 |
| 1990 | 185 | 0.25 | 185 | 0.29 | 185 | 0.13 | 185 | 0.44 | 185 | 0.18 |
| 1991 | 162 | 0.24 | 162 | 0.28 | 162 | 0.13 | 162 | 0.42 | 162 | 0.17 |

# EARTH ORIENTATION PARAMETERS, SITE POSITIONS WITH ESTIMATED SITE VELOCITIES, AND SOURCE POSITIONS FROM THE NASA CRUSTAL DYNAMICS PROJECT USING AM0-2 AND TWO-MONTH STEPWISE POSITIONS FOR HRAS 085: SOLUTION GLB832 GSFC 92 R 02

C. Ma, Code 921, Goddard Space Flight Center, Greenbelt, Md. 20771, USA
D. S. Caprette, Hughes STX, 4400 Forbes Blvd., Lanham, Md. 20706, USA
J. W. Ryan, Code 926, Goddard Space Flight Center, Greenbelt, Md. 20771, USA

Mark III VLBI data acquired since 1979 by the NASA Crustal Dynamics Project, POLARIS/IRIS, the Geographical Survey Institute (Japan), the USNO Navnet, and the US Naval Research Laboratory celestial reference frame program have been analyzed for Earth orientation parameters, the terrestrial reference frame and the celestial reference frame. The terrestrial reference frame origin is set to be near the ITRF90 origin and is defined by the a priori position of the 18-m Westford antenna on 1988 Jan. 1. The orientation of the frames is defined by values from the USNO one-day concrete EOP series and the standard J2000.0 precession and IAU 1980 nutation models for the reference date 1986 Nov. 5 and by the position of WESTFORD and the direction of the WESTFORD-RICHMOND baseline, which evolve according to the AM0-2 model. The right ascension origin is defined by the a priori position of 0420-014.

Short period tidal terms in UT1 have not been removed from the tabulated values of UT1-UTC. Since the solution contains all geodetic (both large and small network) and astrometric sessions, editing criteria based on the quality of the results (uncertainties and correlations) should be applied before using the EOP tables.

The 3-dimensional velocities of all sites with sufficient data were estimated except for HRAS 085, RICHMOND, KAUAI, and MATERA. The position of HRAS 085 was estimated from two-month intervals of data (and tabulated by the starting epoch) to allow for nonuniform motion. Apart from the motion of the AM0-2 model, the position of RICHMOND was constrained to change only in the a priori direction of WESTFORD. The vertical rate of KAUAI was constrained to be zero to provide a more robust geometry. The data for MATERA were weaker than the normal criteria for velocity estimates, but the horizontal components were nonetheless estimated because they appeared to be large and geophysically plausible. The positions of four sites (YAKATAGA, SOURDOGH, FORTORDS, and PRESIDIO) each had one discontinuous change in position related to seismic events. The position of the site following the seismic event, propagated before and after the event, is marked with "ep" in the site position tables. Also, the assumed Gregorian date of the event appears to the right of the last data field in the same tables. The velocities of several sets of sites (FORT ORD-FORTORDS, KASHIMA-KASHIM34, KAUAI-HALEAKAL, MOJAVE12-MOJ 7288-DSS15, OVRO 130-OVR 7853, SESHAN25-SHANGHAI) 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.

~100 sources used in the geodetic programs form the core of the celestial reference frame. ~250 sources have formal errors under 1 mas. The remaining sources include a number that have very weak data. Both delay and delay rate data were used for astrometric and source survey sessions.

All uncertainties are 1-sigma formal standard errors from the sequential least-squares solution GLB832 described below.

The basic models used to calculate the VLBI delays are consistent with the IERS standards and are contained in the Goddard CALC 7.4 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, CfA 2.2 dry troposphere mapping, DE200 solar system ephemeris, and a modified Hellings (1986) VLBI time delay consistent with the alternative IERS standard model at 1 ps rms. The a priori pole position for each observation was interpolated linearly from the one-day USNO concrete series. The a priori UT1 value for each observation was derived from the one-day USNO concrete series by first removing the IERS standard tidal model, interpolating linearly to the epoch of observation, then restoring the standard tidal model. 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 dry troposphere was modeled from local meteorological data and the residual wet troposphere was estimated using a continuous piecewise-linear function with the wet Chao model. 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. The provisions for stepwise positions, episodic motion and linking site velocities are the major changes from our previous submissions.

843523 dual-frequency Mark III delays and 23726 delay rates from 1677 sessions using fixed stations and mobile sites were combined to estimate site positions and velocities, source positions, Earth orientation parameters, and troposphere and clock behavior from a least-squares solution with 1465 global parameters and 328302 arc parameters. There were 664590.9 degrees of freedom. A weak input covariance on polar motion and UT1 (X,Y - 45 mas, UT1 - 3 ms) was used so that all three components could be estimated for each session with more reliable indication of uncertainty and correlation. The weighted rms post-fit residual of the solution was 42.5 ps for delays and 79.7 fs/s for rates. The reduced chi-square was 1.01 including the constraints for the wet troposphere, clocks, and EOP in the computation of the degrees of freedom (Theil, 1963).

The complete Earth orientation time series is designated EOP(GSFC)92 R 02. Other results are source positions designated RSC(GSFC)92 R 02 and site coordinates at 1979-92 Jan 1.5 designated SSC(GSFC)92 R 02.

## References

Hellings, R. W., 1986: *Astron. J.*, **91**, 1446.
Theil, H., 1963: *Amer. Stat. Ass. J.*, **58**, 401.

SUMMARY DESCRIPTION FOR SOLUTION GSFC 92 R 02: SEE P. 15

# EARTH ORIENTATION PARAMETERS, SITE POSITIONS WITH ESTIMATED SITE VELOCITIES, AND SOURCE POSITIONS FROM THE NASA CRUSTAL DYNAMICS PROJECT USING NUVEL-1 AND TWO-MONTH STEPWISE POSITIONS FOR HRAS 085: SOLUTION GLB833 GSFC 92 R 03

C. Ma, Code 921, Goddard Space Flight Center, Greenbelt, Md. 20771, USA
D. S. Caprette, Hughes STX, 4400 Forbes Blvd., Lanham, Md. 20706, USA
J. W. Ryan, Code 926, Goddard Space Flight Center, Greenbelt, Md. 20771, USA

Mark III VLBI data acquired since 1979 by the NASA Crustal Dynamics Project, POLARIS/IRIS, the Geographical Survey Institute (Japan), the USNO Navnet, and the US Naval Research Laboratory celestial reference frame program have been analyzed for Earth orientation parameters, the terrestrial reference frame and the celestial reference frame. The terrestrial reference frame origin is set to be near the ITRF90 origin and is defined by the a priori position of the 18-m Westford antenna on 1988 Jan. 1. The orientation of the frames is defined by values from the USNO one-day concrete EOP series and the standard J2000.0 precession and IAU 1980 nutation models for the reference date 1986 Nov. 5 and by the position of WESTFORD and the direction of the WESTFORD-RICHMOND baseline, which evolve according to the NUVEL-1 model. The right ascension origin is defined by the a priori position of 0420-014.

Short period tidal terms in UT1 have not been removed from the tabulated values of UT1-UTC. Since the solution contains all geodetic (both large and small network) and astrometric sessions, editing criteria based on the quality of the results (uncertainties and correlations) should be applied before using the EOP tables.

The 3-dimensional velocities of all sites with sufficient data were estimated except for HRAS 085, RICHMOND, KAUAI, and MATERA. The position of HRAS 085 was estimated from two-month intervals of data (and tabulated by the starting epoch) to allow for nonuniform motion. Apart from the motion of the NUVEL-1 model, the position of RICHMOND was constrained to change only in the a priori direction of WESTFORD. The vertical rate of KAUAI was constrained to be zero to provide a more robust geometry. The data for MATERA were weaker than the normal criteria for velocity estimates, but the horizontal components were nonetheless estimated because they appeared to be large and geophysically plausible. The positions of four sites (YAKATAGA, SOURDOGH, FORTORDS, and PRESIDIO) each had one discontinuous change in position related to seismic events. The position of the site following the seismic event, propagated before and after the event, is marked with "ep" in the site position tables. Also, the assumed Gregorian date of the event appears to the right of the last data field in the same files. The velocities of several sets of sites (FORT ORD-FORTORDS, KASHIMA-KASHIM34, KAUAI-HALEAKAL, MOJAVE12-MOJ 7288- DSS15, OVRO 130-OVR 7853, SESHAN25-SHANGHAI) 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.

~100 sources used in the geodetic programs form the core of the celestial reference frame. ~250 sources have formal errors under 1 mas. The remaining sources include a number that have very weak data. Both delay and delay rate data were used for astrometric and source survey sessions.

All uncertainties are 1-sigma formal standard errors from the sequential least-squares solution GLB833 described below.

The basic models used to calculate the VLBI delays are consistent with the IERS standards and are contained in the Goddard CALC 7.4 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, CfA 2.2 dry troposphere mapping, DE200 solar system ephemeris, and a modified Hellings (1986) VLBI time delay consistent with the alternative IERS standard model at 1 ps rms. The a priori pole position for each observation was interpolated linearly from the one-day USNO concrete series. The a priori UT1 value for each observation was derived from the one-day USNO concrete series by first removing the IERS standard tidal model, interpolating linearly to the epoch of observation, then restoring the standard tidal model. 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 dry troposphere was modeled from local meteorological data and the residual wet troposphere was estimated using a continuous piecewise-linear function with the wet Chao model. 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. The use of NUVEL-1 and the provisions for stepwise positions, episodic motion and linking site velocities are the major changes from our previous submissions.

843523 dual-frequency Mark III delays and 23726 delay rates from 1677 sessions using fixed stations and mobile sites were combined to estimate site positions and velocities, source positions, Earth orientation parameters, and troposphere and clock behavior from a least-squares solution with 1465 global parameters and 328302 arc parameters. There were 664590.9 degrees of freedom. A weak input covariance on polar motion and UT1 (X,Y - 45 mas, UT1 - 3 ms) was used so that all three components could be estimated for each session with more reliable indication of uncertainty and correlation. The weighted rms post-fit residual of the solution was 42.5 ps for delays and 79.7 fs/s for rates. The reduced chi-square was 1.01 including the constraints for the wet troposphere, clocks, and EOP in the computation of the degrees of freedom (Theil, 1963).

The complete Earth orientation time series is designated EOP(GSFC)92 R 03. Other results are source positions designated RSC(GSFC)92 R 03 and site coordinates at 1979-92 Jan 1.5 designated SSC(GSFC)92 R 03.

## References

Hellings, R. W., 1986: *Astron. J.*, **91**, 1446.
Theil, H., 1963: *Amer. Stat. Ass. J.*, **58**, 401.

SUMMARY DESCRIPTION FOR SOLUTION GSFC 92 R 03: SEE P. 15

# EARTH ORIENTATION PARAMETERS, SITE POSITIONS WITH ESTIMATED SITE VELOCITIES, AND SOURCE POSITIONS FROM THE NASA CRUSTAL DYNAMICS PROJECT USING ESTIMATED EARTH ORIENTATION RATES, AM0-2 AND TWO-MONTH STEPWISE POSITIONS FOR HRAS 085: SOLUTION GLB834 GSFC 92 R 04

C. Ma, Code 921, Goddard Space Flight Center, Greenbelt, Md. 20771, USA
D. S. Caprette, Hughes STX, 4400 Forbes Blvd., Lanham, Md. 20706, USA
J. W. Ryan, Code 926, Goddard Space Flight Center, Greenbelt, Md. 20771, USA

Mark III VLBI data acquired since 1979 by the NASA Crustal Dynamics Project, POLARIS/IRIS, the Geographical Survey Institute (Japan), the USNO Navnet, and the US Naval Research Laboratory celestial reference frame program have been analyzed for Earth orientation parameters, the terrestrial reference frame and the celestial reference frame. The terrestrial reference frame origin is set to be near the ITRF90 origin and is defined by the a priori position of the 18-m Westford antenna on 1988 Jan. 1. The orientation of the frames is defined by values from the USNO one-day concrete EOP series and the standard J2000.0 precession and IAU 1980 nutation models for the reference date 1986 Nov. 5 and by the position of WESTFORD and the direction of the WESTFORD-RICHMOND baseline, which evolve according to the AM0-2 model. The right ascension origin is defined by the a priori position of 0420-014.

The x and y-pole position and UT1 for each day were modeled as offsets and rates from the a priori series. Short period tidal terms in UT1 have not been removed from the tabulated values of UT1-UTC. Since the solution contains all geodetic (both large and small network) and astrometric sessions, editing criteria based on the quality of the results (uncertainties and correlations) should be applied before using the EOP tables.

The 3-dimensional velocities of all sites with sufficient data were estimated except for HRAS 085, RICHMOND, KAUAI, and MATERA. The position of HRAS 085 was estimated from two-month intervals of data (and tabulated by the starting epoch) to allow for nonuniform motion. Apart from the motion of the AM0-2 model, the position of RICHMOND was constrained to change only in the a priori direction of WESTFORD. The vertical rate of KAUAI was constrained to be zero to provide a more robust geometry. The data for MATERA were weaker than the normal criteria for velocity estimates, but the horizontal components were nonetheless estimated because they appeared to be large and geophysically plausible. The positions of four sites (YAKATAGA, SOURDOGH, FORTORDS, and PRESIDIO) each had one discontinuous change in position related to seismic events. The position of the site following the seismic event, propagated before and after the event, is marked with "ep" in the site position tables. Also, the assumed Gregorian date of the event appears to the right of the last data field in the same files. The velocities of several sets of sites (FORT ORD-FORTORDS, KASHIMA-KASHIM34, KAUAI-HALEAKAL, MOJAVE12-MOJ 7288-DSS15, OVRO 130-OVR 7853, SESHAN25-SHANGHAI) 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.

~100 sources used in the geodetic programs form the core of the celestial reference frame. ~250 sources have formal errors under 1 mas. The remaining sources include a number that have very weak data. Both delay and delay rate data were used for astrometric and source survey sessions.

All uncertainties are 1-sigma formal standard errors from the sequential least-squares solution GLB834 described below.

The basic models used to calculate the VLBI delays are consistent with the IERS standards and are contained in the Goddard CALC 7.4 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, CfA 2.2 dry troposphere mapping, DE200 solar system ephemeris, and a modified Hellings (1986) VLBI time delay consistent with the alternative IERS standard model at 1 ps rms. The a priori pole position for each observation was interpolated linearly from the one-day USNO concrete series. The a priori UT1 value for each observation was derived from the one-day USNO concrete series by first removing the IERS standard tidal model, interpolating linearly to the epoch of observation, then restoring the standard tidal model. 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 dry troposphere was modeled from local meteorological data and the residual wet troposphere was estimated using a continuous piecewise-linear function with the wet Chao model. 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. The estimation of EOP rates and the provisions for stepwise positions, episodic motion and linking site velocities are the major changes from our previous submissions.

843523 dual-frequency Mark III delays and 23726 delay rates from 1677 sessions using fixed stations and mobile sites were combined to estimate site positions and velocities, source positions, Earth orientation parameters and rates, and troposphere and clock behavior from a least-squares solution with 1465 global parameters and 333333 arc parameters. There were 660630.8 degrees of freedom. A weak input covariance on polar motion and UT1 (X,Y - 45 mas, UT1 - 3 ms) was used so that all three components could be estimated for each session with more reliable indication of uncertainty and correlation. Weak constraints were also applied to the EOP rates. The weighted rms post-fit residual of the solution was 42.0 ps for delays and 79.5 fs/s for rates. The reduced chi-square was 0.99 including the constraints for the wet troposphere, clocks, and EOP in the computation of the degrees of freedom (Theil, 1963).

The complete Earth orientation time series is designated EOP(GSFC)92 R 04. Other results are source positions designated RSC(GSFC)92 R 04 and site coordinates at 1979-92 Jan 1.5 designated SSC(GSFC)92 R 04.

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SUMMARY DESCRIPTION FOR SOLUTION GSFC 92 R 04: SEE P. 15

**Summary description of the solutions GSFC 92 R 01, 92 R 02, 92 R 03 and 92 R 04**

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.
- The definitions of the origins of the terrestrial reference frames in the four submitted solutions are explained in the individual notes included for each solution.
- A priori calibration of the 'dry' atmosphere via CfA-2.2 model atmosphere with either in situ measurements of pressure and temperature or site-dependent static values.
- No a priori calibration of the 'wet' atmosphere.
- Residual wet atmosphere modeled 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 Chao 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.e-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.
- Quasar source positions estimated globally except for the right ascension of the quasar 0420-014, which is used to define the origin of right ascension of the celestial reference frame.

2) Analysis Center:

GSFC - the VLBI group of the Crustal Dynamics Project of the Goddard Space Flight Center.

3) Solution Identifier:

There are 4 solutions for this submission GLB831, GLB832, GLB833, and GLB834.

4) Software used:

CALC 7.4, 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:

AM0-2 in GLB831, GLB832 and GLB834, NUVEL in GLB833

8) Velocity of light:

2.99792458E+8 m/s

9) Geogravitational constant:

Not applicable.

10) Reference epoch:
1986 November 05 for both earth rotation and nutation, 1988 January 1 for site velocities. Source coordinates are J2000.0.

11) Adjusted parameters:
Dependent on details of solution but include: earth orientation, daily nutation offsets, epoch station positions and velocities, globally estimated source positions, and session-dependent clock and atmosphere parameters.

12) Definition of the origin:
The origin of the terrestrial reference frame is fixed by the adopted position of the Westford antenna at 1988 January 1 and the AM0-2 model for GLB831, GLB832 and GLB834, or the NUVEL model for GLB833. The origin is close to ITRF90 at the site velocity reference epoch.

13) Definition of the orientation:
The orientation of the terrestrial reference frame is defined by the a priori EOP values on the reference day (1986 Nov 05) from the USNO concrete EOP series and by the direction of the WESTFORD to RICHMOND baseline which evolved according to AM0-2 for GLB831, GLB833 and GLB834, and according to NUVEL for GLB834. 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 and the a priori right ascension of 0420-014.

14) Evolution with time:
The stations with insufficient data are constrained to move with AM0-2 velocities in GLB831, GLB832 and GLB834, and with NUVEL in GLB833. Westford's position and the direction from Westford to Richmond are constrained to evolve by the same model. With the exception of the vertical rates at the stations noted in the individual solution descriptions, the 3-dimensional velocities of stations with sufficient data are freely adjusted.

EARTH ROTATION PARAMETERS FROM DSN VLBI: 1992 JPL 92 R 01

J.A. Steppe, S.H. Oliveau, O.J. Sovers
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, USA

In mid-1991 the X band spanned bandwidth used in the VLBI observations of the TEMPO project was substantially increased, resulting in improved precision in the earth orientation results.

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. Each observing session uses antennas in 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 1992 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 285 observations of 50 to 100 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 1992 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 1992-1 (see below) determined radio source coordinates, station coordinates, and a parametric model for the celestial motion of the Celestial Ephemeris Pole. 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. Such clock breaks are rare in TEMPO sessions but more common in the longer duration CAT M&E sessions.

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. 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 aprioris is negligible and the estimated troposphere zenith delays are essentially completely determined by the VLBI observables.)

Other properties of the ERP solution were:

1. Stations move with plate tectonic motion as specified by the Minster-Jordan AM0-2 model.

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 1992-1 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.)

We derived formal errors by adding an "additive noise" constant to the square of each raw observable error to make the Chi Square of the postfit residuals 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 826 observing sessions between October 28, 1978, and March 8, 1992.

During calendar year 1991, the TEMPO project produced earth rotation measurements from 95 dual frequency observing sessions, with a median standard error along the minor axis of the error ellipse of 0.4 milliarcseconds (mas), and along the major axis of 1.8 mas. During 1991 the median turnaround time for TEMPO measurements, from observation to availability of earth orientation parameters, was 2 days.

Since the X band spanned bandwidth was increased on June 12, 1991, through March 8, 1992, the TEMPO project has produced earth rotation measurements from 74 dual frequency observing sessions, with a median standard error along the minor axis of the error ellipse of 0.3 mas, and along the major axis of 1.4 mas.

JPL 1992-1 CATALOG

The JPL 1992-1 catalog was developed specifically for use in TEMPO operational ERP solutions during 1992. Since short duration VLBI determinations of the ERP are sensitive to errors in the 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 1992-1 catalog solution. Although this CEP model has the form of adjustments to the coefficients of the IAU precession-nutation model, it is intended only to permit processing of TEMPO data for the ERP during the period reported here and during 1992, and will presumably need revision in 1993. In particular, it may not include all significant components and all its parameters may not be well separated, but we believe it is adequate for our purposes.

The JPL 1992-1 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 23,1991, and most of the TEMPO data through January 21, 1992, were included.

3. Information from intra-complex radio interferometry and ground surveys was used to constrain the coordinate differences between stations within each complex (with a standard deviation of 1 cm).

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 SPACE91 series (Gross, 1992) 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. There were 65 such pairs of TEMPO sessions; there were 4 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.

5. The terrestrial frame of the JPL 1992-1 system was tied to the International Earth Rotation Service Terrestrial Reference Frame ITRF-88 (IERS, 1989, Table T-4) 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 14, DSS 43, and DSS 63. These constraints are such that if a seven parameter transformation (3 translations, 3 rotations, 1 scale) between the JPL 1992-1 and ITRF-88 systems were estimated by unweighted least squares applied to the coordinates of DSS 14, 43, and 63, 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 1 cm; 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-88.

6. 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 IERS Celestial Reference Frame ICRF-88 (and are still primary in ICRF-90), were held fixed at their values in ICRF-88 as specified in the set of radio source coordinates RSC(IERS)89 C 01 (IERS, 1989, Table C-3). By this means the coordinate system of the JPL 1992-1 RSC is tied to the IERS celestial frame ICRF-88. (The Right Ascension of 3C 273 was NOT held fixed.) 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)92 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.

7. The reference epoch of the JPL 1992-1 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 model of the celestial motion of the CEP obtained as part of the JPL 1992-1 catalog solution is presented below as adjustments to the IAU precession and 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. This year the CEP-motion model includes 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.

Site velocities were estimated in preliminary solutions performed to assist in selecting the final parameters of the catalog solution. The adjusted velocity parameters represented incremental velocities in addition to the velocities implied by the AM0-2 model. All stations in each DSN complex were assumed to have the same incremental site velocity. The incremental velocities were constrained so as to produce no net translation rate and no net rotation rate (relative to that implied by AM0-2) for the network composed of the three DSN complexes. Thus the estimated velocities represent the rate of deformation of the network (again relative to that implied by AM0-2); no attempt was made to estimate any net motion of the network relative to other sites in the IERS Terrestrial Reference Frame. 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. The estimated values for the incremental velocities of the three Cartesian coordinates of each site were a few millimeters per year with formal uncertainties of a few millimeters per year. We judged these incremental velocities to be not genuinely significant, and decided not to estimate site velocities in the JPL 1992-1 catalog solution.

Celestial Ephemeris Pole Motion Model

| Index | Period days | Phase | Component | Adjustment mas | Formal Error mas | Generalized Error mas |
|---|---|---|---|---|---|---|
| precession | | | Longitude | -2.84/yr | 0.12/yr | 0.38/yr |
| Y-offset | | | L sin eps | -16.70 | 0.62 | 2.16 |
| X-offset | | | Obliquity | + 1.64 | 0.21 | 0.22 |
| 1 | -6798.38 | In | Longitude | - 7.71 | 0.64 | 1.65 |
| | | | Obliquity | + 1.72 | 0.11 | 0.12 |
| | | Out | Longitude | + 2.56 | 0.30 | 1.34 |
| | | | Obliquity | + 2.80 | 0.06 | 0.09 |
| 2 | -3399.19 | In | Longitude | + 2.47 | 0.31 | 0.45 |
| | | | Obliquity | + 0.03 | 0.07 | 0.08 |
| 10 | 365.26 | In | Longitude | + 4.89 | 0.14 | 0.18 |
| | | | Obliquity | + 2.03 | 0.05 | 0.06 |
| | | Out | Longitude | + 1.40 | 0.13 | 0.16 |
| | | | Obliquity | - 0.53 | 0.05 | 0.06 |
| 9 | 182.62 | In | Longitude | + 1.42 | 0.09 | 0.12 |
| | | | Obliquity | - 0.48 | 0.04 | 0.05 |
| | | Out | Longitude | - 1.05 | 0.10 | 0.14 |
| | | | Obliquity | - 0.54 | 0.04 | 0.05 |
| 31 | 13.66 | In | Longitude | + 0.22 | 0.09 | 0.17 |
| | | | Obliquity | + 0.07 | 0.04 | 0.07 |
| | -429.8 | In | Longitude | - 0.15 | 0.15 | 0.16 |
| | | | Obliquity | + 0.11 | 0.05 | 0.05 |
| | | Out | Longitude | - 0.79 | 0.12 | 0.16 |
| | | | Obliquity | - 0.04 | 0.05 | 0.06 |

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 1992-1 catalog solution and reported here. Approximate values are:

| Baseline | Latitude (°) | Longitude (°) |
|---|---|---|
| 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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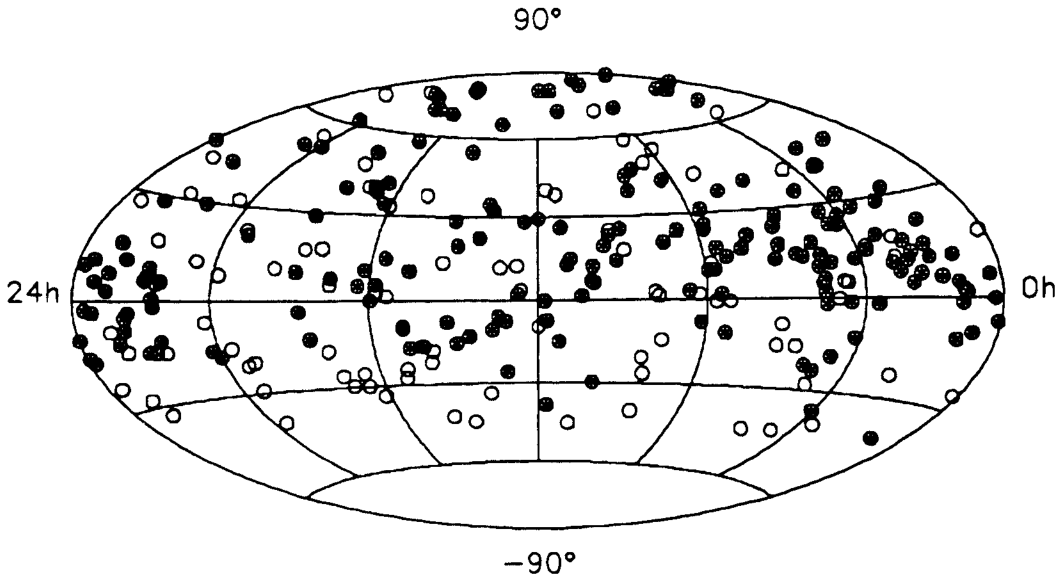
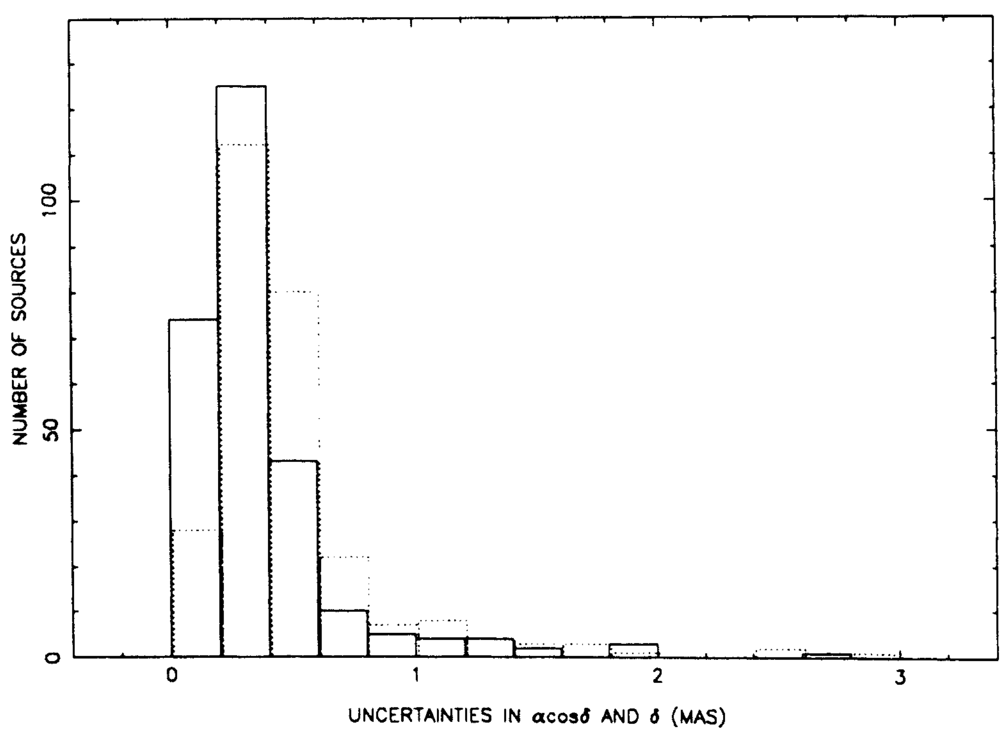
## Summary description of the terrestrial system attached to the set of station coordinates SSC(JPL) 92 R 01.

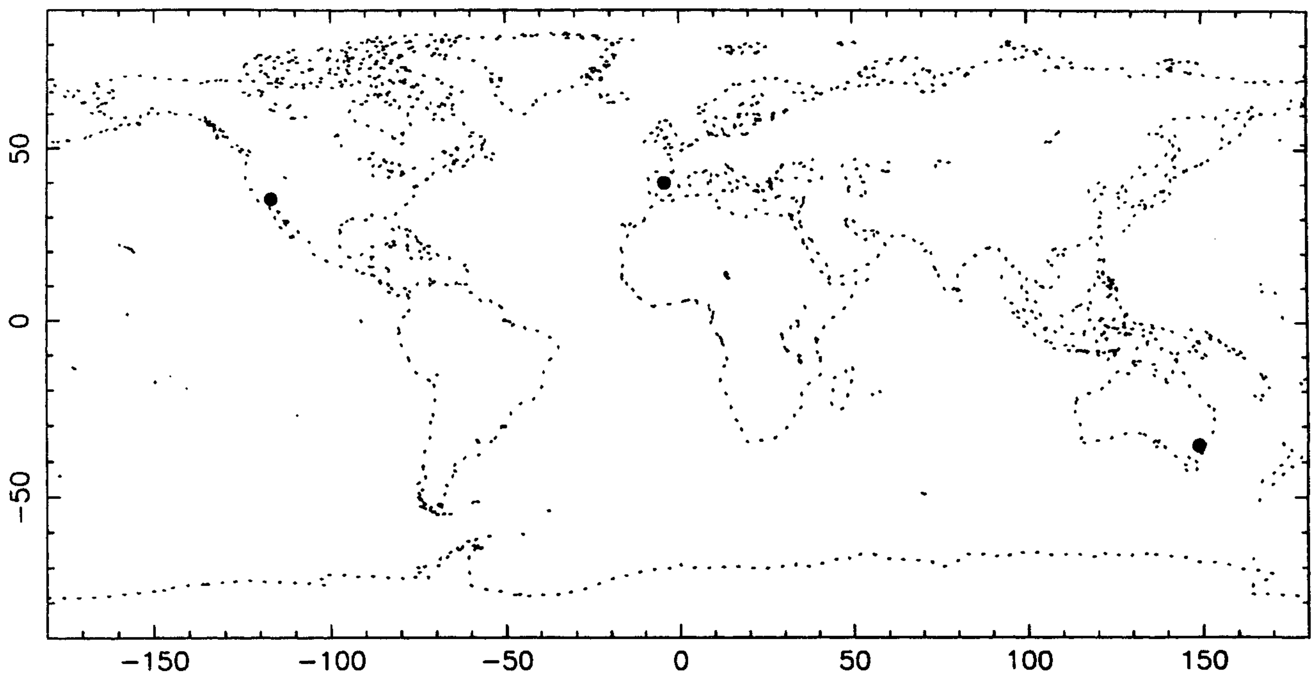
1 - Technique : VLBI
2 - Analysis Center : JPL
3 - Solution identifier : 1992-1
4 - Software used : MODEST (nee Masterfit)
5 - Relativity scale : LE (TDT = geocentric with IAT)
6 - Permanent tidal correction : No
7 - Tectonic plate model : AM0-2
8 - Velocity of light : 299 792 458 m/s
9 - Geogravitational constant : 3.9860 0448 *10**14 m**3*s**-2
10 - Reference epoch : 1 Jan 1988
11 - Adjusted parameters : X0, Y0, Z0
12 - 13 Definition of the origin and orientation: Six constraints were applied (with 1cm uncertainty) to the nine coordinates of DSS 14, DSS 43, and DSS 63, such that if a seven parameter transformation (3 translations, 3 rotations, 1 scale) between the JPL 1992-1 and ITRF-88 systems were estimated by unweighted least squares applied to the coordinates of DSS 14, 43, and 63, 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 : AM0-2 model.



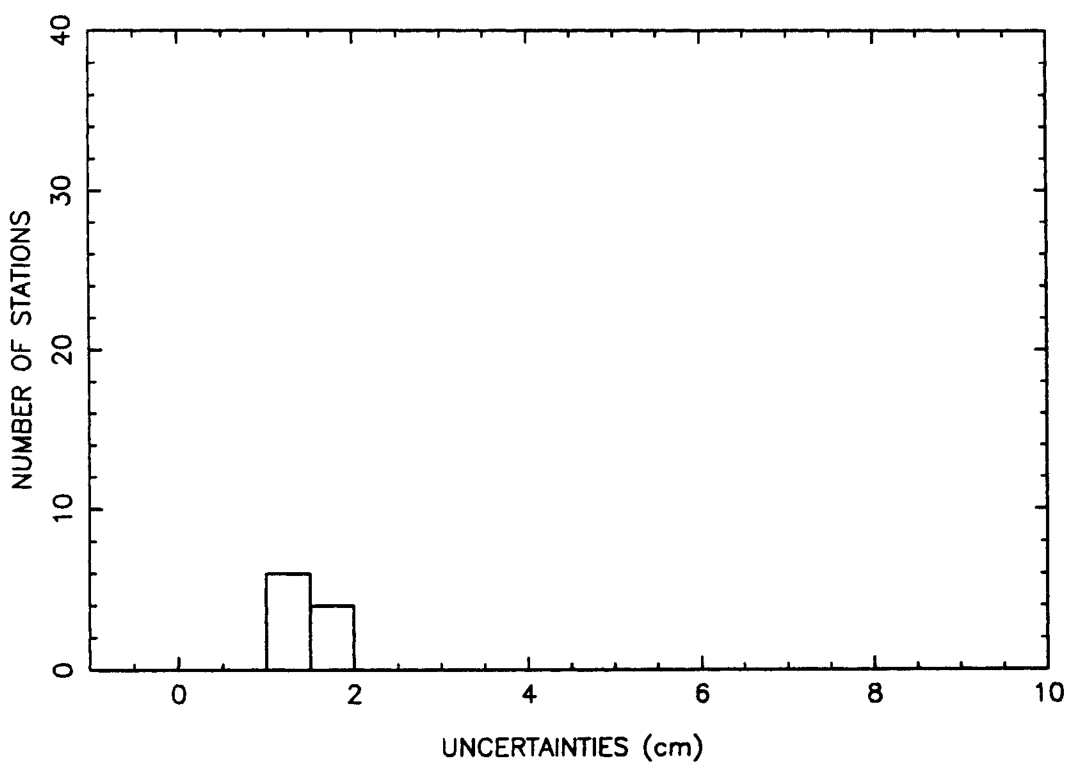

Distribution over the sky of the 282 extragalactic radio sources of the celestial frame RSC(JPL) 92 R 01.Circles with asterisks indicate radio sources with uncertainties in right ascension (αcosδ) and declination smaller than 0.0005".




Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(JPL) 92 R 01.11 radio sources with uncertainties larger than 0.003" are not shown.




Distribution of the 3 sites of the terrestrial frame SSC(JPL) 92 R 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 10 stations of the terrestrial frame SSC(JPL) 92 R 01.

EOP(JPL) 92 R 01 From Oct 1978 to Mar 1992

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

| YEAR | φ | | UT0 | |
|---|---|---|---|---|
| | Nb | Sigma | Nb | Sigma |
| 1978 | 3 | 0.46 | 3 | 1.21 |
| 1979 | 6 | 1.77 | 6 | 1.95 |
| 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 | 72 | 2.83 | 72 | 3.39 |
| 1987 | 77 | 2.07 | 77 | 3.35 |
| 1988 | 93 | 1.70 | 93 | 2.31 |
| 1989 | 93 | 0.71 | 93 | 1.71 |
| 1990 | 108 | 0.92 | 108 | 1.81 |
| 1991 | 110 | 0.55 | 110 | 1.05 |
| 1992 | 19 | 1.00 | 19 | 0.81 |

# SMOOTHED, STANDARD-COORDINATE EARTH ROTATION FROM DEEP SPACE NETWORK VLBI: 1992 JPL 92 R 02

J.A. Steppe, R.S. Gross, O.J. Sovers, S.H. Oliveau
Jet Propulsion Laboratory, California Institute of Technology - Pasadena, California 91109, USA

NASA's Deep Space Network (DSN) makes regular measurements of the orientation of the earth using Very Long Baseline Interferometry (VLBI). The primary analysis of these data (Steppe, *et al.*, 1992) has been submitted to the International Earth Rotation Service (IERS) under the name EOP (JPL) 92 R 01. Since these measurements use single-baseline VLBI, each observing session can measure only two components of the earth orientation, and these are not aligned with the standard components PMX, PMY, and UT1; the primary analysis reports the results as measurements of the UT0 and variation of latitude of the baseline vector. The relation of these components to the standard components depends on the specific pair of stations forming the baseline, and this varies from session to session. Making good use of the information content of these measurements requires a proper treatment of the coordinate transformations involved and full use of the reported correlation coefficients associated with the measurement uncertainties. At JPL these capabilities have been incorporated in a Kalman Earth Orientation Filter (KEOF).

The Central Bureau of the IERS has invited the analysis centers to submit additional solutions of earth rotation measurements in order to clarify the analyses of the IERS. In the spirit of that invitation, this report attempts to facilitate intercomparisons of the DSN VLBI earth rotation data set with other earth rotation data sets by providing an earth orientation time series in the standard components that is derived entirely from the DSN VLBI results; of necessity any such series must be a smoothed series. The series we have chosen to report was obtained by a Kalman smoothing of EOP (JPL) 92 R 01. We recommend that for purposes of forming a combined determination of the earth orientation from results of various measurement programs, the Kalman smoothed results reported here not be used; for this purpose the primary results EOP (JPL) 92 R 01 should be used directly.

In contrast to most other uses of KEOF (*e.g.*, Gross 1992), no bias-rate corrections were applied before smoothing. Thus the results reported here are referred to the same celestial and terrestrial reference frames as EOP (JPL) 92 R 01; that is, RSC (JPL) 92 R 01 and SSC (JPL) 92 R 01. Also, no adjustments have been applied before smoothing to the claimed uncertainties from EOP (JPL) 92 R 01.

The effect of the tides upon UT1 was removed before smoothing by using the models of Yoder *et al.* and of Brosche *et al.*, including suitably attenuated versions of the diurnal and semidiurnal oceanic tidal terms; (for details see Gross (1992) ). All these tidal terms except for the diurnal and semidiurnal terms were added back to the UT1 values after smoothing.

In the type of smoothing reported here (called an "included" smoothing), the KEOF produced output vectors only at the times of the input measurements, and in producing each output vector made use of the input measurement at that time (as well as the input measurements at other times). Thus the temporal density of the filter output vectors exactly reflects the temporal density of the input measurements, and each output vector depends to a considerable degree on the measurement at that same time. The direction in the parameter space of earth orientation that cannot be measured by the baseline used at that time is called the degenerate direction. The component of the Kalman filter output vector in the degenerate direction depends entirely on interpolation from measurements at other times. If a particular measurement is widely separated in time from the nearest measurement on any other baseline, then there will be a large interpolation uncertainty in the degenerate direction of that measurement, and hence large uncertainties on the PMX, PMY, UT1 results from the Kalman filter at that time. The many data gaps in the early years of the DSN VLBI programs cause many of the PMX, PMY, UT1 uncertainties to be large during those years. Conversely, the near completeness of the TEMPO series in recent years makes this smoothing a viable method of presenting results for the last few years. Because of this effect, we have chosen to report the results of the smoothing only for times after 1990.0.

The degree of smoothing in the reported ("included" smoothing) series has been examined by comparing the uncertainties of the reported series with those of a similar "excluded" smoothing. An "excluded" smoothing (like an "included" smoothing) produces output vectors only at the times of the input measurements, but in producing each output vector does NOT use the input measurement at that time (unlike an "included" smoothing which DOES use the input measurement at that time). This comparison indicated that the filter output in the best determined direction of a particular measurement depends mostly on that measurement, and not on measurements at other times. Even for the weakly determined direction of a particular measurement, the filter output depends mostly on that one measurement, at least for most times. Therefore, the time scale of the smoothing in the reported series is, for any fixed direction in PMX, PMY, UT1 space, quite variable, ranging from about 0.1 days to roughly 10 days, and is highly dependent on which baseline was observed at the time in question, and on the time separation to the nearest measurement on the other baseline.

In order to convey the precession-nutation model used in determining EOP (JPL) 92 R 01, and hence EOP (JPL) 92 R 02 as well, the values implied by the model for Delta-Psi and Delta-Epsilon at the times of the measurements have been included in the reported series. These values have been computed from the celestial ephemeris pole motion model obtained in the JPL 1992-1 solution (Steppe *et al.*, 1992), and include the effects of the precession, X-offset, and Y-offset parameters, as well as the adjustments to the nutation amplitudes. Since these values depend on the entire history of DSN VLBI, rather than on any short time span, we have chosen to not present any uncertainties for them. These Delta-Psi and Delta-Epsilon values are referred to the celestial reference frame RSC (JPL) 92 R 01, which is itself closely tied to the IERS celestial reference frame.

**Acknowledgements.** 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.

**References:**

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Steppe, J. A., Oliveau, S.H.and Sovers, O.J., 1992: Earth Rotation Parameters from DSN VLBI: 1992, *IERS Technical Note 11*, Observatoire de Paris, p. 17.

EOP(JPL) 92 R 02 From Jan 1990 to Mar 1992

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 |
| 1990 | 108 | 1.17 | 108 | 0.59 | 108 | 0.85 | 108 | | 108 | |
| 1991 | 110 | 0.81 | 110 | 0.44 | 110 | 0.67 | 110 | | 110 | |
| 1992 | 18 | 0.76 | 18 | 0.42 | 18 | 0.49 | 18 | | 18 | |

# NOTES ON THE METHOD AND REFERENCE FRAMES FOR THE EARTH ROTATION ESTIMATION NAOMZ 92 R 01

Seiji Manabe - Division of Earth Rotation, National Astronomical Observatory

## 1. Data

VLBI observations spanning from January 4, 1984 to December 26, 1991 are used to estimate the ERP, station positions and proper motions, and radio source coordinates. The contributing networks are IRIS-A, -P, -S, NAVNET and CDP. NAVEX and CDP with mobile stations are not used. The total number of the used databases is 824.

## 2. Physical models

The basic physical models used in the analyses are the same as the IERS standards(McCarthy *et al.* 1989) and CALC7. However, there are some differences as summarized below.

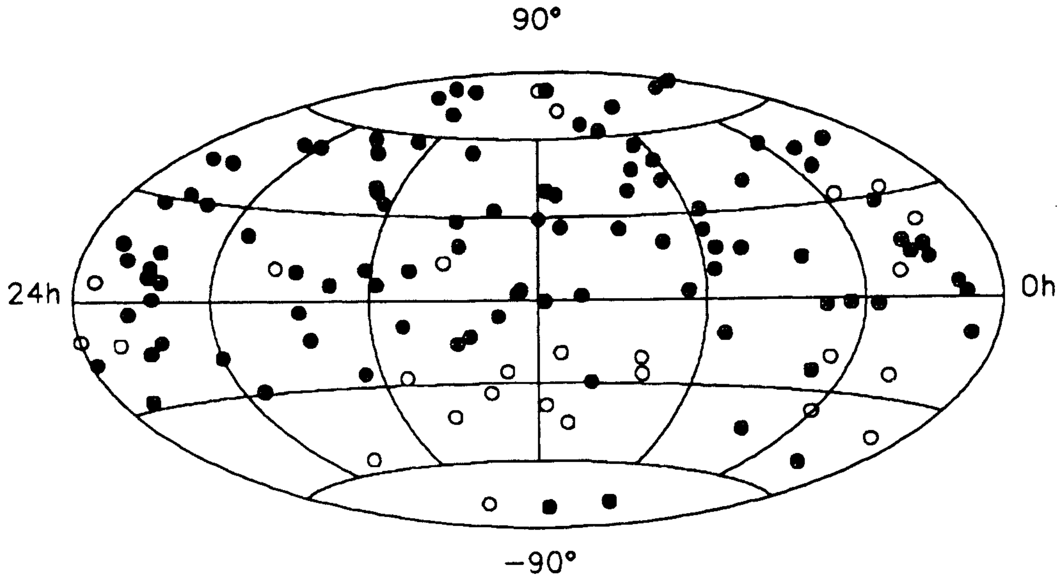
| | |
|---|---|
| Relativistic time delay | : Fukushima(1991) with DE200 as planetary ephemerides. |
| Solid earth tide | : Cartwright, Taylor and Edden expansion of the tidal potential. The permanent tide is taken into account. The frequency dependent love numbers by Wahr (1981) are used in the diurnal band. |
| Ocean tidal loading | : The amplitude and phased computed with GOTIC(Sato and Hanada (1985)) are used. Schwiederski's tidal maps for M2, S2, O1, K1, N2, P1, K2, Q1 and Mf are used. |
| Atmospheric loading | : Vertical displacement is corrected for by using the analytic approximations by Manabe, which is expressed as delta_u=a*cos(2 pi t) + b*sin(2 pi t) + c*delta_p, where t is the observation epoch in fraction of year. The mean of the observed surface pressure is used as a reference pressure for each station. |

## 3. Reference frames

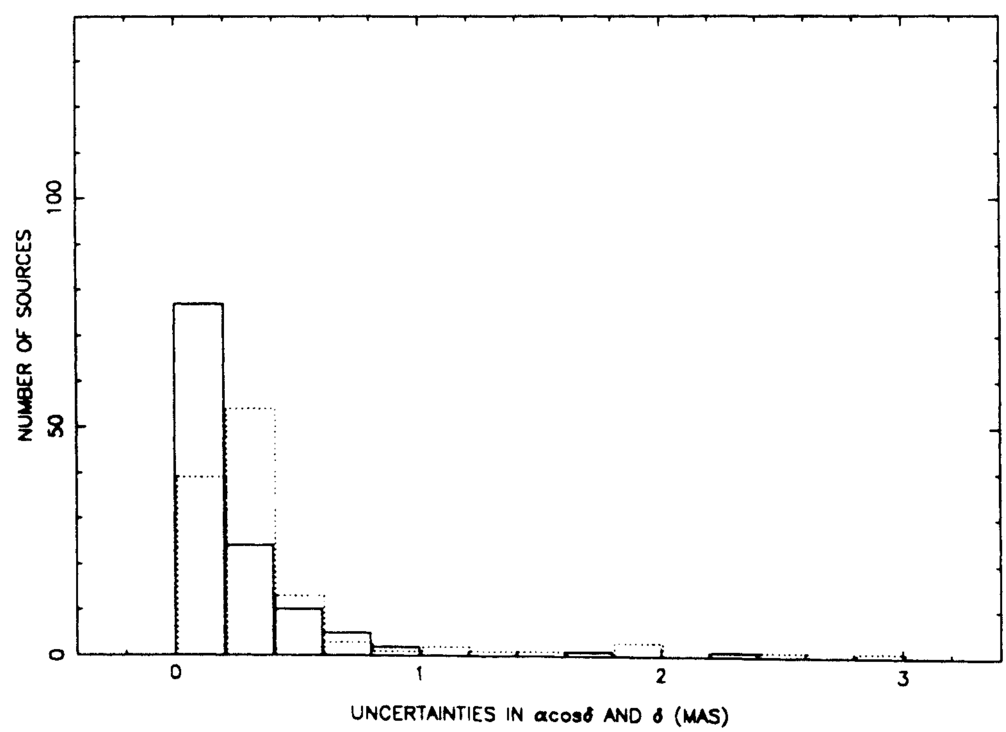
The coordinates of WESTFORD are fixed to those in ITRF90 and assumed to move along with AM0-2 plate motion. The mean orientation of GILCREEK, NRAO85 3, MOJAVE12, HRAS 085, WETTZELL, RICHMOND, WESTFORD, KAUAI, KASHIMA and ONSALA60 is fixed to ITRF90 at Jan. 1, 1988 and assumed to move along with AM0-2. GILCREEK, MOJAVE12, HRAS 085, WETTZELL, RICHMOND, KAUAI, KASHIMA and ONSALA60 are allowed to move linearly with time with respect to AM0-2 in the solution. The mean right ascension of the IERS primary sources is fixed to ICRF90. The mean longitude and obliquity are also fixed for the primary sources.

## 4. Analysis method

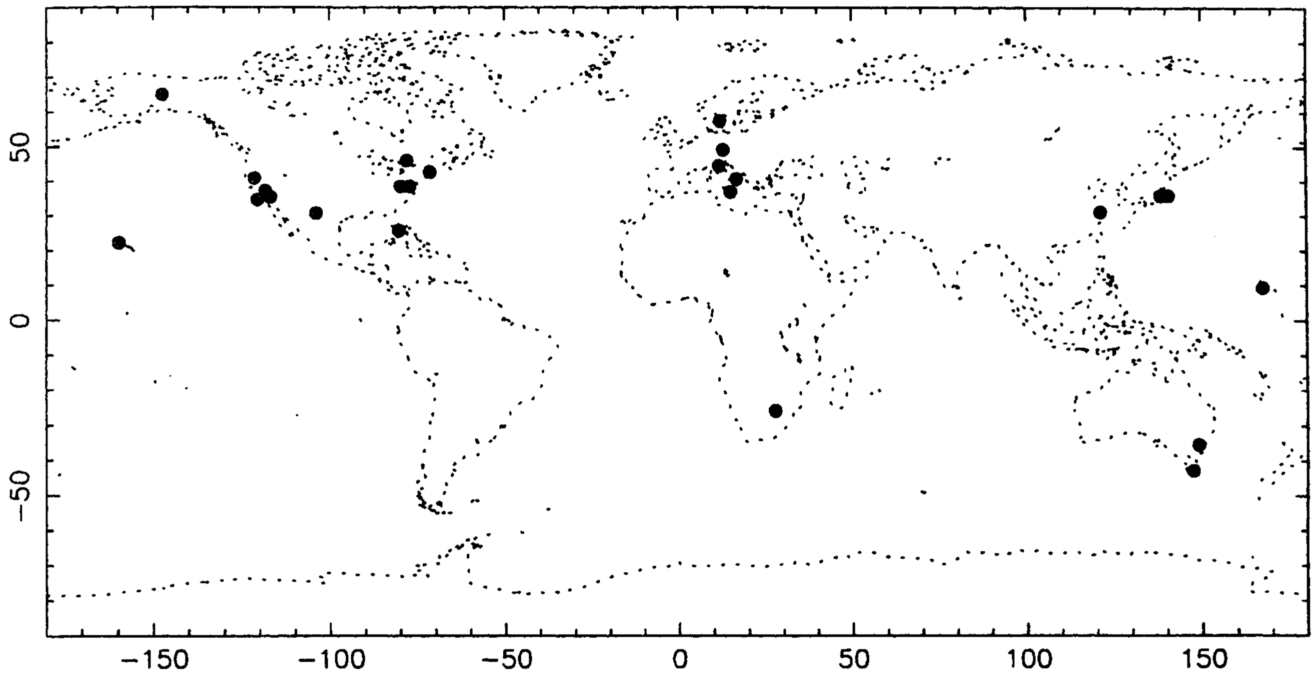
In the first step individual databases are analysed separately. Epochs and degrees of clock polynomials are determined. Tukey's M-estimate is used and weights automatically assigned with this method are used in the later global analysis. In the second step all the databases are treated as if they consist of one large database. Changes of the zenith path length are approximated by piecewise continuous linear segments with damping parameter of 5.e-11 sec/sec for variation rate. We had to change and rewrite our program of the global analysis because the program used last year required too many computer resources and could not be run. The program was shrinked to allow only linear variations for the station coordinates and constant offsets for source coordinates. In this reduced method it is prac-tical to compute variances of the estimated parameters. However, they are not included in the report.



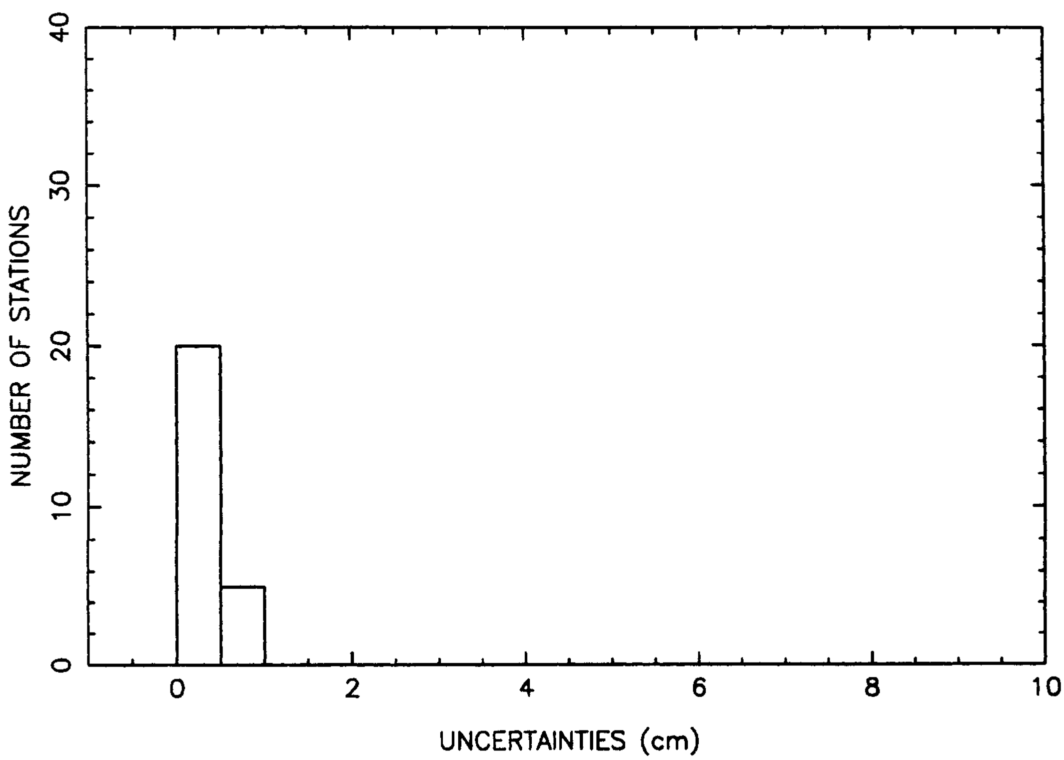

Distribution over the sky of the 125 extragalactic radio sources of the celestial frame RSC(NAOMZ) 92 R 01. Circles with asterisks indicate radio sources with uncertainties in right ascension ($\alpha\cos\delta$) and declination smaller than 0.0005".




Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(NAOMZ) 92 R 01. 5 radio sources with uncertainties larger than 0.003" are not shown.




Distribution of the 24 sites of the terrestrial frame SSC(NAOMZ) 92 R 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 25 stations of the terrestrial frame SSC(NAOMZ) 92 R 01.

EOP(NAOMZ) 92 R 01 From Jan 1984 to Dec 1991

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 |
| 1984 | 76 | 0.52 | 76 | 0.48 | 76 | 0.25 | 76 | 0.66 | 76 | 0.24 |
| 1985 | 81 | 0.57 | 81 | 0.51 | 81 | 0.26 | 81 | 0.68 | 81 | 0.25 |
| 1986 | 93 | 0.57 | 93 | 0.51 | 93 | 0.27 | 93 | 0.68 | 93 | 0.26 |
| 1987 | 103 | 0.64 | 103 | 0.57 | 103 | 0.31 | 103 | 0.80 | 103 | 0.29 |
| 1988 | 106 | 0.57 | 106 | 0.52 | 106 | 0.29 | 106 | 0.68 | 106 | 0.27 |
| 1989 | 121 | 0.49 | 121 | 0.50 | 121 | 0.25 | 121 | 0.69 | 121 | 0.27 |
| 1990 | 141 | 0.27 | 141 | 0.29 | 141 | 0.14 | 141 | 0.41 | 141 | 0.17 |
| 1991 | 101 | 0.27 | 101 | 0.28 | 101 | 0.15 | 101 | 0.38 | 101 | 0.15 |

# EARTH ORIENTATION TIME SERIES DERIVED FROM VLBI OBSERVATIONS

NOAA 92 R 01
NOAA 92 R 02

W.E. Carter, D.S. Robertson, and J.R. Ray, Geosciences Laboratory, N/OES13, NOS NOAA, Rockville, Maryland 20852, USA

Estimated values for Earth orientation parameters (EOP) have been derived for each observing day in a composite set of Mark III Very Long Baseline Interferometry (VLBI) data collected under the aegis of projects MERIT (Wilkins, 1984), POLARIS and IRIS (Carter *et al.*, 1985), and the NASA Crustal Dynamics Project. 523,835 group delay observations amassed during 936 one-day observing sessions conducted between September 1980 and February 1992 were combined in a single least-squares adjustment to obtain self-consistent EOP time series (EOP (NOAA) 92 R 01), coordinates for 77 radio sources (RSC (NOAA) 92 R 01) (see Robertson *et al.*, 1986), and coordinates and velocities of the VLBI reference points for 31 radio telescopes (SSC (NOAA) 92 R 01). In addition, a separate series of daily UT1 values for the period April-June 1984 and April 1985 through February 1992 has been produced (EOP (NOAA) 92 R 02). These UT1 values were determined from a series of special observing sessions using only the Westford-Wettzell baseline for 45 minutes each day (Robertson *et al.*, 1985). These restricted observing sessions are sufficient to determine only UT1.

The observations were processed at NOAA using algorithms generally consistent with the IERS standards (McCarthy, 1989), which include use of the IAU 1980 nutation model (with adjustment; see below), an Earth tide model based on ephemeris positions for the Sun and Moon with the K1 term removed, Wahr's (1985) model for the solid Earth deformations resulting from the motion of the pole, and a model for ocean loading displacements. Shapiro's formulation for the relativistic effects of signal propagation was used (1983a; 1983b) (see also Herring, 1989 and Ryan, 1989). The algorithm includes effects of the positions and velocities of the stations and the relativistic effects of the gravity field of both the Sun and the Earth. Shapiro's algorithm yields theoretical delays that agree within 2 picoseconds (<1 mm equivalent path length) of the algorithm developed by Hellings (1986), when gravitational effects on the radio wave propagation in the vicinity of the Earth are added to the latter. Refraction due to the "dry" (hydrostatic) portion of the neutral atmosphere was modeled according to Saastamoinen (1972) in the local zenith direction and mapped to line-of-sight elevations with the CfA-2.2 model (Davis et al., 1985), using surface meteorological data (pressure, temperature, humidity) taken at each VLBI station during each observing session. Residual atmospheric delay, presumably due to the "wet" troposphere, was treated by adjusted parameters (see below) using the elevation mapping function of Chao (1972) for a typical water vapor distribution. The dispersive portion of the atmospheric refraction (due to the ionosphere) was eliminated by the use of simultaneous dual-frequency (X- and S- band) observations. No adjustments were made to account for atmospheric loading or 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.

The data were processed in a single least-squares solution which first passes forward through the full data set to determine values for the global parameters (those whose values are affected by all observing sessions) followed by a step to determine the arc parameters (those affected only by data from a single observing session). The geocentric coordinates of the stations, the velocities of the stations, and the celestial coordinates of the radio sources were determined globally. Arc parameters model both nuisance effects (clock and atmospheric delays) and the important EOP variations (X and Y pole position and UT1). In addition, the accuracy of the VLBI observations is sufficient to warrant daily adjustments to the IAU 1980 nutation model (in longitude and obliquity). Herring *et al.* (1986) have reported significant errors in the annual, semi-annual, and fortnightly terms of the IAU nutation model. Time variations in the station clock differences were treated by estimating coefficients of polynomials, usually one or two second-order polynomial segments per day. Residual ("wet") atmospheric delays were 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 of 50 ps per hour was applied to the variation of the atmosphere parameters between break-points.

The unconstrained estimation of global station coordinates, station velocities, and source coordinates, together with daily EOP values, is singular. The following conventions provide a minimal, but non-unique, set of constraints to remove this singularity. The right ascension origin of the celestial frame is fixed by requiring the average right ascension adjustment for nine well observed sources be zero. The a priori source coordinates are from a previously determined set wherein the right ascension of 3C273B had been fixed to 12h 29m 6.6997s. The origin of the terrestrial reference frame is fixed by adopting geocentric coordinates for Westford, Massachusetts at the epoch 1988.0 which resulted from a translation to match the VLBI and satellite laser ranging (SLR) origins (NEOS, 1991). In this way, the VLBI origin is closely aligned with the center of mass of the Earth. The scale of the terrestrial frame is set by the combined effects of the analysis algorithms described above (especially the models for general relativity and atmospheric propagation) and the speed of light, and has been found to agree with the SLR scale within about 1E- 09 (IERS, 1991). If the VLBI points remained fixed within the terrestrial frame, the rotational ambiguity between the terrestrial and celestial frames could be removed by adopting a single set of EOP values at a specified epoch (assuming the radio sources are perfectly stationary). However, terrestrial motions are significant, due to tectonic and other processes. Estimating three components of velocity for each station introduces six additional singularities into the definition of the terrestrial reference system, three for the velocity of the origin and three rotational singularities. The velocity of the center of the system was constrained by fixing the Westford velocity to the AM0-2 North American plate value (Minster and Jordan, 1978). The rotational singularities were removed by fixing the values of pole position and UT1 at a second reference epoch, rather than one as in the past. The two reference dates, 25 October 1985 and 27 January 1990, were selected to minimize differences with previous polar motion and UT1 series. The nutation reference date remains 25 October 1985. The computed station coordinates (SSC (NOAA) 92 R 01) have been propagated to epoch 01 January 1988 using the estimated station velocities, except for two sites with data spans less than a few months for which AM0-2 velocities were used.

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 unmodeled systematic errors. Based on comparisons with GPS determinations, we estimate that since the Wettzell observatory became operational in January 1984 the IRIS X and Y components of polar motion have had uncertainties no worse than 0.5 milliseconds of arc (Herring *et al.*, 1991). Comparisons between the 5-day and the daily UT1 values (see below) indicates that both series are accurate to at least ± 0.1 milliseconds of time (Robertson *et al.*, 1985).

The intensive UT1 observations use a single baseline from Wettzell in Germany to Westford in Massachusetts. Eight observations are made on four different sources within a one-hour observing session. The observations are processed in a combined solution which contains all of the rest of the observations. Only UT1 and a clock offset and rate are adjusted for each intensive observation. Robertson, *et al.*, 1985 estimated the total uncertainty in the intensive UT1 determinations to be about 0.1 millisecond of time.

On behalf of the joint International Association of Geodesy (IAG), Committee on Spa Research (COSPAR) Subcommission International Radio Interferometric Surveying (IRIS), NOAA distributes the monthly IRIS Bulletin A, Earth Orientation Information, and maintains a file containing the same data on the NOAA computers which can be accessed via telephone by users who would prefer a machine-readable form. Additional information or assistance concerning the data presented here, or the data available through the INTERNET, MARK 3, IRIS Bulletin A, or NOAA computer system may be obtained by contacting the authors.

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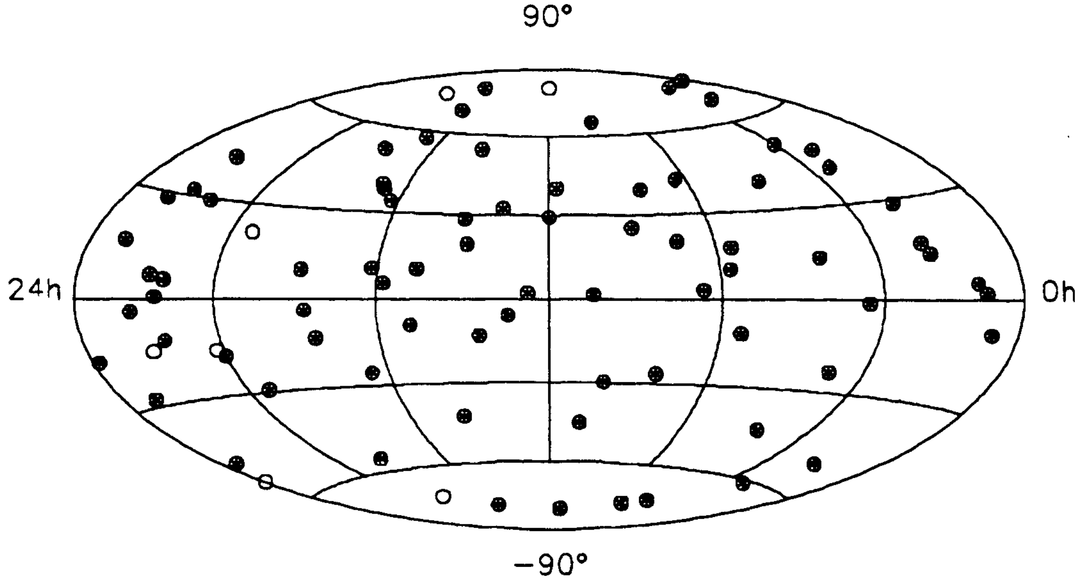
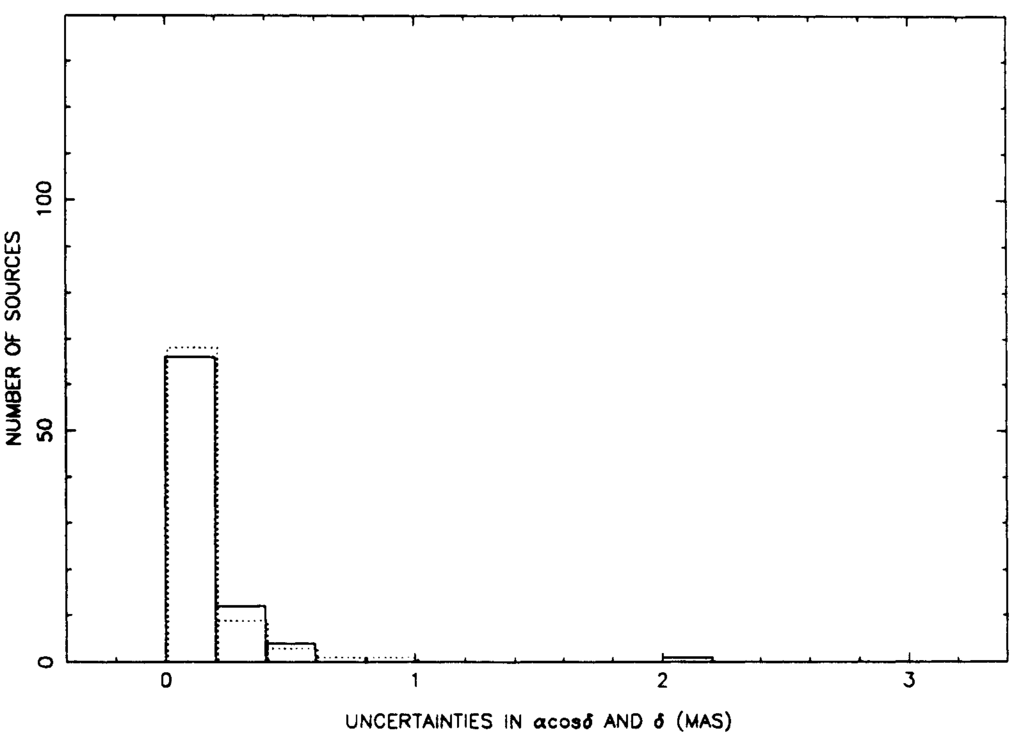
**Summary description of the terrestrial system attached to the set of station coordinates SSC(NOAA) 92 R 01**

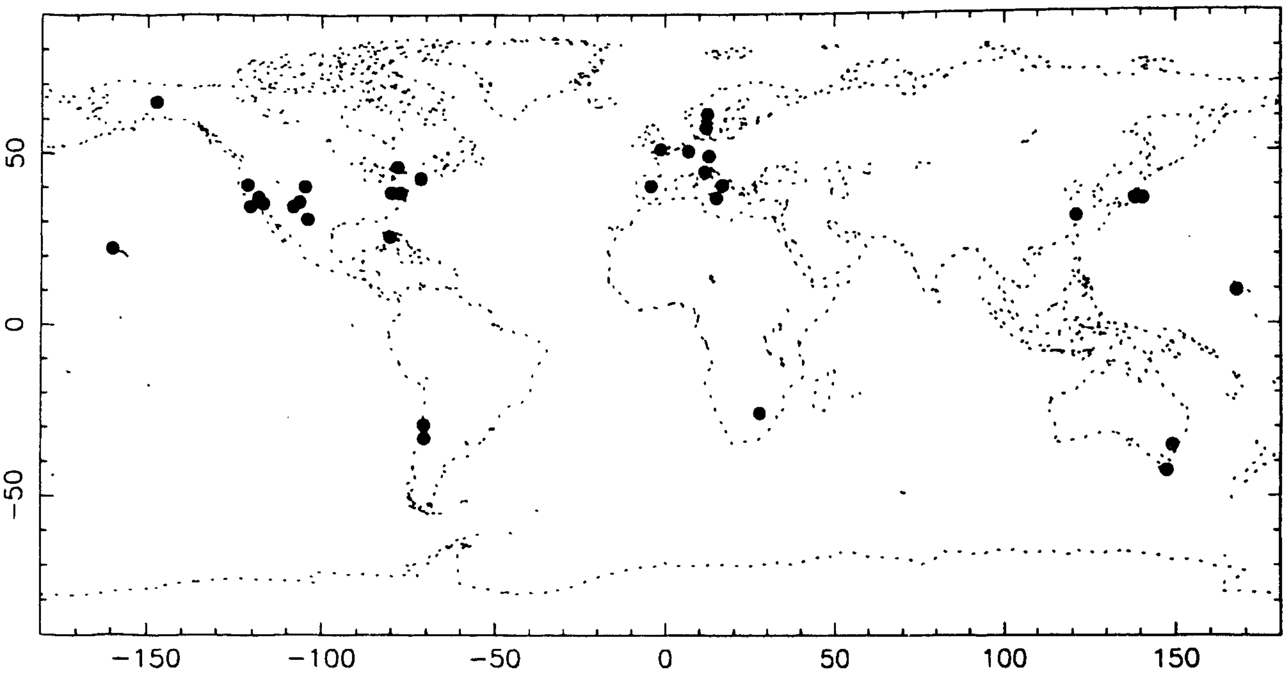
| | |
|---|---|
| 1 - Technique: | VLBI |
| 2 - Analysis Center: | NOAA |
| 3 - Solution Identifier: | SSC(NOAA) 92 R 01 |
| 4 - Software Used: | CALC |
| 5 - Relativity Scale: | SSB |
| 6 - Permanent Tidal Correction on Station: | Yes |
| 7 - Tectonic Plate Model: | AM0-2, with station velocities adjusted |
| 8 - Velocity of Light: | 299792458 |
| 9 - Geogravitiational Constant: | not relevant |
| 10 - Reference Epochs: Station Coordinates: | 1/1/1988 |
| Nutation: | |
| Pole Position/UT1: | |
| 11 - Adjusted Parameters: | see description above |
| 12 - Definition of the Origin: | Westford Coordinates fixed--see table |
| 13 - Definition of the Orientation: | EOP values adopted at two epochs (see number 10) |
| 14 - Constraint for Time Evolution: | See 10 and 13. |



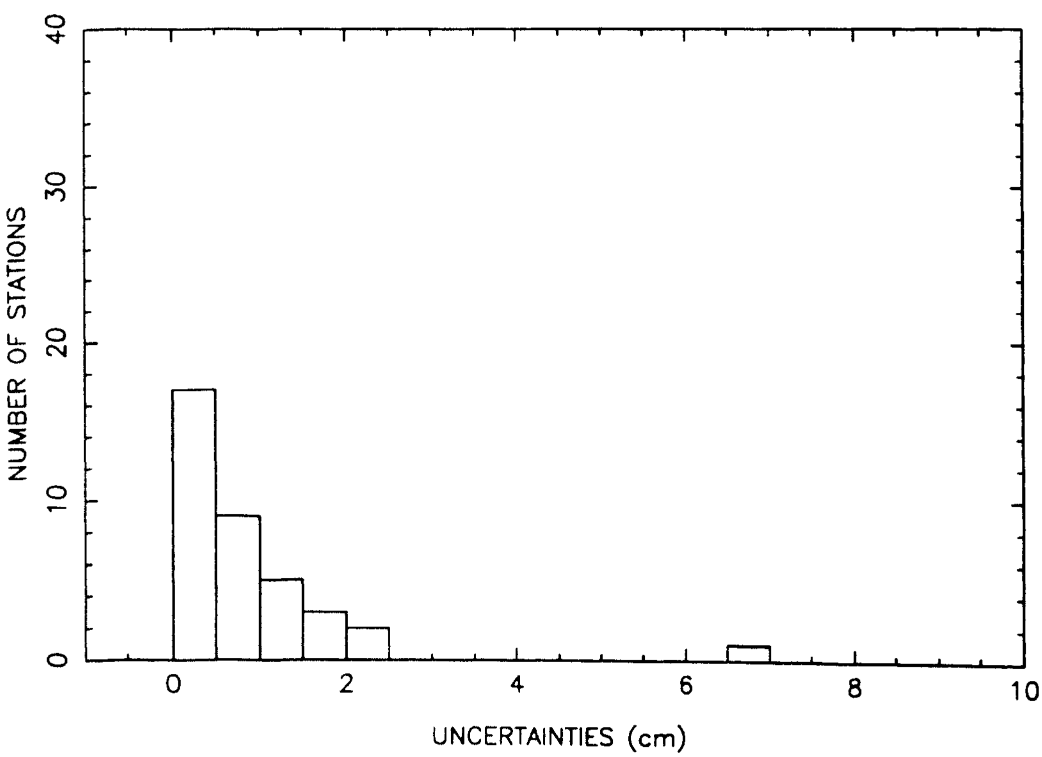

Distribution over the sky of the 84 extragalactic radio sources of the celestial frame RSC(NOAA) 92 R 01. Circles with asterisks indicate radio sources with uncertainties in right ascension ($\alpha\cos\delta$) and declination smaller than 0.0005".




Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(NOAA) 92 R 01. 1 radio source with uncertainty larger than 0.003" is not shown.




Distribution of the 33 sites of the terrestrial frame SSC(NOAA) 92 R 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 37 stations of the terrestrial frame SSC(NOAA) 92 R 01.

EOP(NOAA) 92 R 01 From Sep 1980 to Feb 1992

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 |
| 1980 | 16 | 0.99 | 16 | 1.05 | 16 | 0.51 | 16 | 1.12 | 16 | 0.38 |
| 1981 | 6 | 1.25 | 6 | 1.35 | 6 | 0.68 | 6 | 1.43 | 6 | 0.51 |
| 1982 | 10 | 1.25 | 10 | 1.17 | 10 | 0.57 | 10 | 2.00 | 10 | 0.56 |
| 1983 | 17 | 1.12 | 17 | 1.88 | 17 | 0.79 | 17 | 1.70 | 17 | 0.53 |
| 1984 | 70 | 0.80 | 70 | 0.87 | 70 | 0.43 | 70 | 1.14 | 70 | 0.40 |
| 1985 | 70 | 0.53 | 70 | 0.57 | 70 | 0.28 | 70 | 0.77 | 70 | 0.28 |
| 1986 | 73 | 0.48 | 73 | 0.48 | 73 | 0.24 | 73 | 0.75 | 73 | 0.26 |
| 1987 | 73 | 0.44 | 73 | 0.44 | 73 | 0.21 | 73 | 0.74 | 73 | 0.26 |
| 1988 | 73 | 0.36 | 73 | 0.36 | 73 | 0.18 | 73 | 0.68 | 73 | 0.25 |
| 1989 | 72 | 0.31 | 72 | 0.29 | 72 | 0.15 | 72 | 0.63 | 72 | 0.23 |
| 1990 | 71 | 0.26 | 71 | 0.27 | 71 | 0.13 | 72 | 0.58 | 72 | 0.21 |
| 1991 | 90 | 0.31 | 90 | 0.32 | 90 | 0.15 | 90 | 0.56 | 90 | 0.20 |
| 1992 | 9 | 0.35 | 9 | 0.36 | 9 | 0.17 | 9 | 0.56 | 9 | 0.20 |

EOP(NOAA) 92 R 02 From Apr 1984 to Feb 1992

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

| YEAR | UT1 | |
|---|---|---|
| | Nb | Sigma |
| 1984 | 64 | 1.03 |
| 1985 | 159 | 0.59 |
| 1986 | 237 | 0.61 |
| 1987 | 246 | 0.59 |
| 1988 | 255 | 0.58 |
| 1989 | 234 | 0.60 |
| 1990 | 261 | 0.60 |
| 1991 | 247 | 0.57 |
| 1992 | 20 | 0.39 |

EARTH ORIENTATION PARAMETERS FROM VLBI SHA 92 R 01

Zhao Ming, Chen Gang, Wei Xue, Yang Zhigen, Wang Guanli
Shanghai Observatory, Academia Sinica, Shanghai, P.R.China

The coordinates of the pole and UT1 from January 1990 to September 1991 are estimated for 0h UT on the tabulated dates for all available IRIS Observations. In addition to the Earth Orientation Parameters(EOP), the adjustment includes the estimations of nutation angles, and the atmospheric zenith time delay for each site. The models used in the estimations are consistent with the IERS standards(McCarthy 1989), but the NUVEL-1 plate model is adopted instead of AM0-2 and no model for atmospheric loading is used. Kalman Filter in this processing is used to estimate the parameters mentioned above.

## References

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

EOP(SHA) 92 R 01 From Jan 1990 to Sep 1991

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 |
| 1990 | 70 | 0.22 | 70 | 1.24 | 70 | 0.14 | 70 | 0.40 | 70 | 0.17 |
| 1991 | 41 | 0.19 | 41 | 0.22 | 41 | 0.11 | 41 | 0.36 | 41 | 0.14 |

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

USNO 92 R 03

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

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) to monitor changes in the orientation of the Earth on a regular basis. NEOS is a joint cooperative effort of the USNO and the National Oceanic and Atmospheric Administration (NOAA), and this VLBI program is designed to complement the observations coordinated by the NOAA as part of the International Radio Interferometric Surveying (IRIS) subcommission. The Naval Research Laboratory (NRL) and the Crustal Dynamics Project VLBI group at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) have also assisted in the development of the program. The Navy VLBI Network (NAVNET) measures the orientation of the Earth in space from Mark III VLBI observations acquired with telescopes at Gilmore Creek, Alaska, Kokee Park, Hawaii, Richmond, Florida, Green Bank, West Virginia and, in the past, Maryland Point, Maryland. Radio telescopes at Mojave, California, Westford, Massachusetts, Algonquin Park, Canada, and Medicina and Noto, Italy, have also participated in these experiments. Current NAVNET operations consist of one 24-hour duration observing session per week together with two-hour duration observing sessions on two other days of the week. These NAVNET data are used to estimate UT1, polar motion and nutation for inclusion in the International Earth Rotation Service (IERS) combined solutions. In addition, 1991 saw the continuation of the NAVNET Experimental (or NAVEX) series. All of the currently available 24-hour-duration NAVNET and NAVEX data are provided in this report in a uniform reduction using the Navy 1992-3 reference frame, which will also be described.

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 the Maryland, Alaska, Hawaii and Florida antennas. One 24-hour GNUT was observed in September, 1988; monthly 24-hour NAVNETs commenced in April, 1989, and all of the weekly NAVNETs have been nominally 24 hours in duration since June 27, 1989. At present, one 24-hour NAVNET experiment is scheduled every week using the Florida, Alaska, Hawaii and West Virginia antennas. Starting in May, 1991, the NAVNET schedules were coordinated with the schedules of the IRIS-A experiments arranged by NOAA; since that date the IRIS-A observing sessions nominally start on the Monday, and the NAVNET sessions on the Thursday, of each week. The NAVNET data are reduced and released to NEOS and the IERS on a regular basis; typical processing times are now on the order of 5 days from the acquisition of data to release of the final results for the regular NAVNET data.

In cooperation with the Agenzia Spaziale Italizana, Centro di Geodesia Spaziale, the U.S. Naval Observatory NAVNET VLBI program has initiated 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, and Kashima, Japan, have also participated in NAVEX observations. The major goals of these experiments are to study the sources of systematic error in VLBI Earth orientation measurements and to investigate the observed 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. NAVEX results are included in Tables 6, 7 and 8 with the other NAVNET Earth orientation data.

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 are spread across 85 MHz at S band and 350 MHz at X band, using the "Old" channel frequencies shown in Table 1, In 1991 the potential spanned bandwidth was nearly doubled and a series of tests were performed to prepare for the operational use of this upgrade using the "New" channel frequencies shown in Table 1. These tests (on 8/26/91, 9/24/91, 1/14/92, 1/21/92 and 1/28/92) were successful, and operational use of the wider spanned bandwidth began on February 1, 1992. The introduction of these wider spanned bandwidths caused the typical weighted root mean square residual scatter to decrease from ~ 45 picoseconds to ~ 25 to 30 picoseconds.

Table 1 : NAVNET Channel Frequencies

| Channel Number | Band | Old Frequency Setup, MHz | New Frequency Setup, MHz |
|---|---|---|---|
| 1 | S | 2217.99 | 2220.99 |
| 2 | S | 2222.99 | 2230.99 |
| 3 | S | 2237.99 | 2250.99 |
| 4 | S | 2267.99 | 2305.99 |
| 5 | S | 2292.99 | 2340.99 |
| 6 | S | 2302.99 | 2345.99 |
| 1 | X | 8210.99 | 8212.99 |
| 2 | X | 8220.99 | 8252.99 |
| 3 | X | 8250.99 | 8352.99 |
| 4 | X | 8310.99 | 8512.99 |
| 5 | X | 8420.99 | 8732.99 |
| 6 | X | 8500.99 | 8852.99 |
| 7 | X | 8550.99 | 8912.99 |
| 8 | X | 8570.99 | 8932.99 |

The NAVNET VLBI data have all been correlated at the Washington Correlator, which is located on the Naval Observatory grounds and is 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.

After correlation, fringe fitting, and the removal of any remaining bandwidth synthesis delay ambiguities, the NAVNET, NAVEX and GNUT 24-hour-duration multi-baseline data 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. The data are processed with IERS standard models to the maximum extent possible. The GSFC CALC 7.6 software is used in the data reduction process. The Nuvell plate motion model is used without adjustment to describe the tectonic motions of the stations. The CFA 2.2 tropospheric mapping function is used to relate line of sight tropospheric propagation delays to the tropospheric zenith delay. Although the vertical deformations due to ocean tidal loading are modeled in the reduction process, the horizontal deformations are not, and ground deformations due to atmospheric loading are currently ignored.

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.

NAVNET data reduction depends on a reference frame, which is derived from the NAVNET data and is intended to align the NAVNET Earth orientation results as closely as is possible with both the terrestrial and celestial reference frames maintained by the IERS. The new NAVNET reference frame, Navy 92-3, was prepared using 75850 delay and delay rate observation pairs from 167 observing sessions (complete through March 19, 1992). This reduction used the new CALC 7.6 geodetic software created by the NASA GFSC VLBI group. Due to software limitations, the NAVNET reference frame is obtained from the USNO 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 49 radio sources given in Table 2 is held fixed at the value given in the IERS combined celestial reference frame for 1990 (RSC(IERS) 91 C 01). All other source coordinates, and all of the station coordinates except for those of the Richmond station, 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 values. The declinations of two sources, 0202+149 and 0742+103, are then fixed in a second solution to the values obtained in the first solution. This second solution globally adjusts the coordinates of all of the other sources (subject to the same Right Ascension constraint as before) and all of the station coordinates except for the Richmond station, together with an adjustment for UT1, Polar Motion, both components of nutation plus the piecewise linear clock and troposphere models separately for each experiment. The IERS Rapid Service estimates of the UT1 and polar motion are treated as a priori measurements in this solution. The position of the Richmond station at the epoch 1980 October 17 is fixed at the value given by the ITRF-90 adjusted to that epoch using the Nuvell model, and all stations are allowed to move at the Nuvell rate. Four radio sources (3C84, 3C273B, 3C345 and 3C454.3) were judged to have too much source structure to be usable for geodetic work and are no longer observed; these "removed" sources were treated as "arc" parameters in the solution, with a separate position being estimated for each experiment in which they were observed. The USNO reference frame 1992-3 was obtained from such a solution using data from all of the long duration NAVNET and NAVEX VLBI observing sessions from 1987 through March 19, 1992; this solution used a total of 75850 observation pairs (delay and delay rate) with a weighted rms residual scatter of ± 41.7 picoseconds for the delay observations and ± 106.2 femtoseconds per second for the delay rate data. Table 3 describes the stations used in NAVNET operations; the station coordinates for the NAVNET stations from the reference frame solution are available for the epoch 1980 October 17 as well as the corresponding source positions. In the latter the Source Type describes the quality of the position, with Reference ("R") and Primary ("P") sources having the most accurate positions and the Secondary ("S") sources having position formal errors larger than a milli arc second.

Table 2 : Sources used to constrain Right Ascension in the Navy 92-3 reference frame :

| | | | | | |
|---|---|---|---|---|---|
| 0016+731 | 0048-097 | 0106+013 | 0119+041 | 0133+476 | 0201+113 |
| 0229+131 | 0234+285 | 0235+164 | 0300+470 | 0420-014 | 0434-188 |
| 0528+134 | 0552+398 | 0727-115 | OJ287 | 4C39.25 | 0814+425 |
| 1055+018 | 1123+264 | 1144+402 | 1222+037 | 1308+326 | 1334-127 |
| OQ208 | 1418+546 | 1502+106 | 1510-089 | 1519-273 | 1548+056 |
| 1611+343 | 1633+38 | NRAO530 | 1739+522 | 1741-038 | 1749+096 |
| 2121+053 | 2145+067 | 2216-038 | 2234+282 | 2253+417 | 2345-167 |
| 3C279 | 3C418 | CTA26 | CTA102 | NRAO140 | 2128-123 |
| 2243-123 | | | | | |

Table 3 : Stations Participating in the U.S. Navy VLBI Program

| Station | Location | Station ID Code |
|---|---|---|
| GILCREEK | Fairbanks, Alaska | A |
| KAUAI | Kokee Park, Kauai, Hawaii | K |
| RICHMOND | Richmond, Florida | R |
| NRAO85 3 | Green Bank, West Virginia | W |
| MARPOINT | Maryland Point, Maryland | N |
| MOJAVE12 | Mojave, California | M |
| WESTFORD | Westford, Massachussetts | E |
| ALGOPARK | Algonquin Park, Canada | G |
| MEDICINA | Medicina, Italy | B |
| NOTO | Noto, Italy | S |
| MATERA | Matera, Italy | I |
| HARTRAO | Hartebeesthoek R.A.O., South Africa | J |
| WETTZELL | Wettzell, Germany | V |
| SANTIA12 | Santiago, Chile | S |
| KASHIM34 | Kashima, Japan | O |

The NAVNET 24-hour experiments are nominally performed on Thursday and Friday of each week. Earth orientation results from these data are generally available within five days after the end of the experiment, by the Thursday of the week after the experiment. The NAVNET Earth orientation results 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 NAVNET data, as experiments are frequently processed using UT1 predictions. The operational NAVNET solutions now estimate the rate of change of the UT1 averaged over the entire observing session. This solution used a total of 77251 observation pairs (delay and delay rate) and produced weighted rms residual scatters of ± 40.9 picoseconds for the delay observations and ± 106.3 femtoseconds per second for the delay rate data. (This solution included a few more recent experiments than were available for the reference frame solution.) The station coordinates and source positions are fixed at the a priori values given by the Navy 1992-3 reference frame; the positions of the secondary sources and the removed sources are treated as arc parameters, with a separate position being estimated for each experiment in which they were observed. The tie to the 1991-2 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 Earth orientation results with the full covariance information are distributed in the format requested by the IERS Central Bureau, together with a list of the stations participating in the experiments. Note that the Earth orientation parameter 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.

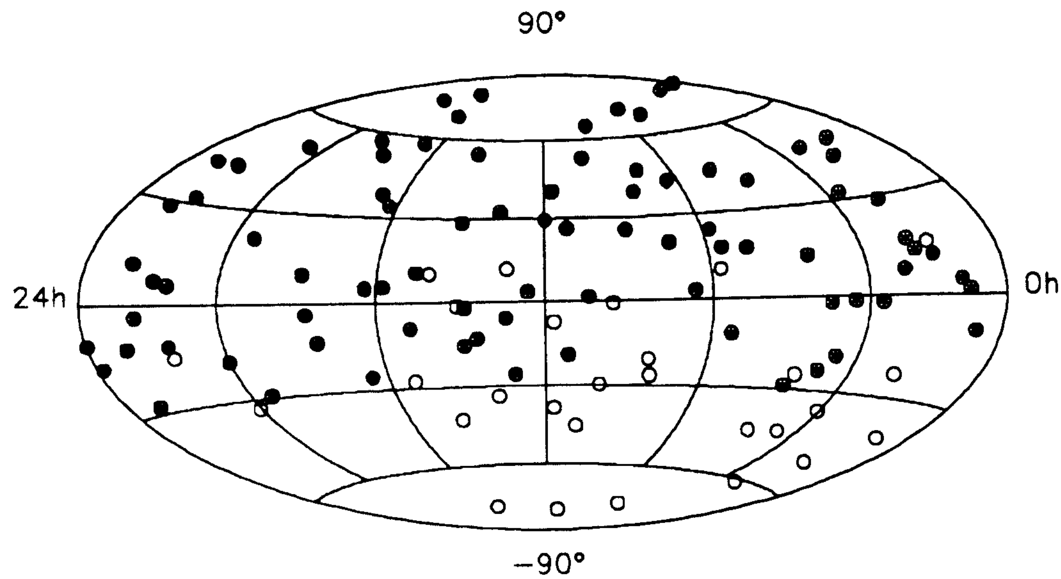
The errors presented in this report are formal errors obtained from the covariance matrix of the least squares adjustment. The post fit residual scatter is always larger than would be expected given the formal error estimates for the delay and delay rate observables provided by the correlator. The total 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 operational NAVNET solutions now estimate the rate of change of the UT1 during each experiment. 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) are also provided on request from the Central Bureau of IERS. They are comparable in accuracy to those obtainable through differencing of successive UT1 offset estimates, and thus make an interesting data product in themselves

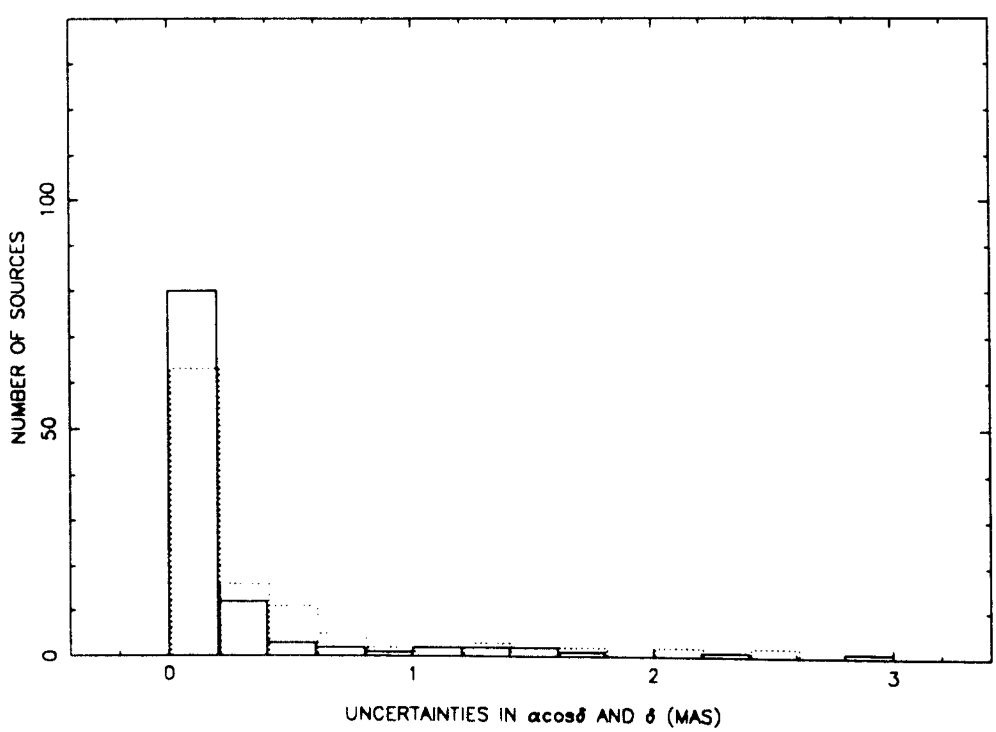
Questions, comments or requests to be placed on the NAVNET distribution list should be directed to T.M. Eubanks, Code TSEO, U.S. Naval Observatory, Washington D.C. 20392-5100, by phone at (202) 653-1501, on SPAN at CDDIS::USNO or USNO01::TME, and on Internet at tme@casa.usno.navy.mil or tme@usno01.usno.navy.mil.

**Summary description of the terrestrial system attached to the set of station coordinates SSC(USNO) 92 R 03 (USNO 1992-3)**

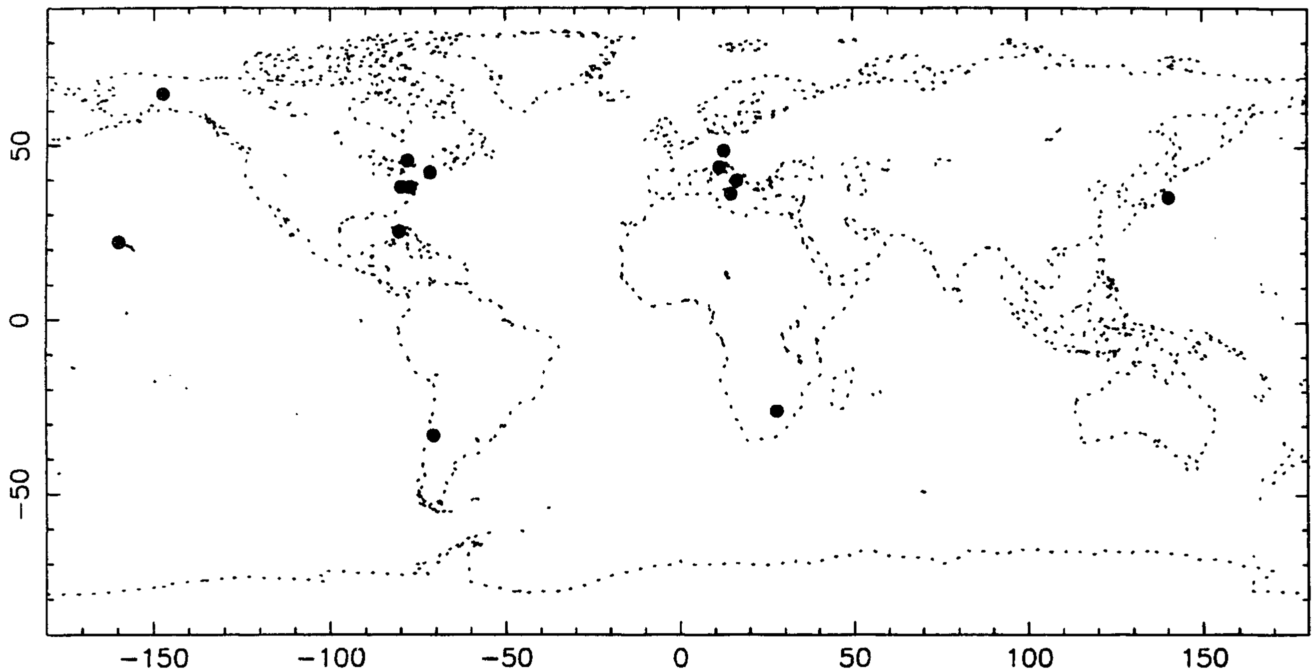
| | |
|---|---|
| 1 - Technique : | VLBI |
| 2 - Analysis Center : | USNO |
| 3 - Solution identifier : | SSC(USNO) 92 R 03 (USNO 1992-3) |
| 4 - Software used : | Calc 7.6 |
| 5 - Relativity scale : | Geocentric |
| 6 - Permanent tidal correction : | No |
| 7 - Tectonic plate model : | Nuvell |
| 8 - Velocity of light : | 299 792 458 m/s |
| 10 - Reference epoch : | 17 October 1980 |
| 11 - Adjusted parameters : | see text |
| 12 - Definition of the origin : | Richmond station position in ITRF-90 |
| 13 - Definition of the orientation : | Mean 49 sources in Right Ascension<br>Mean IERS Bull. A values for UT1, Polar and (indirectly) Nutation |
| 14 - Constraint for time evolution : | Nuvell model |



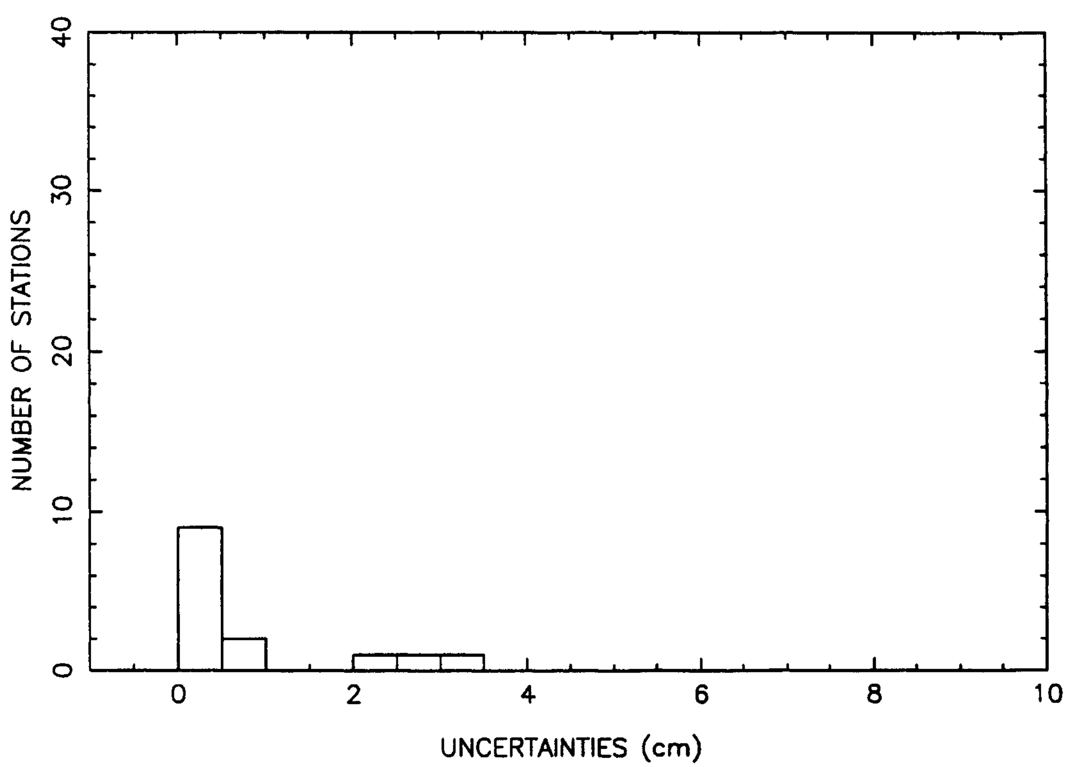

Distribution over the sky of the 113 extragalactic radio sources of the celestial frame RSC(USNO) 92 R 03. Circles with asterisks indicate radio sources with uncertainties in right ascension (αcosδ) and declination smaller than 0.0005".




Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(USNO) 92 R 03. 6 radio sources with uncertainties larger than 0.003" are not shown.




Distribution of the 14 sites of the terrestrial frame SSC(USNO) 92 R 03.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 14 stations of the terrestrial frame SSC(USNO) 92 R 03.

EOP(USNO) 92 R 03 From Dec 1988 to Apr 1992

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 |
| 1988 | 1 | 1.85 | 1 | 1.91 | 1 | 0.89 | 1 | 1.40 | 1 | 0.42 |
| 1989 | 28 | 0.51 | 28 | 0.71 | 28 | 0.30 | 28 | 0.61 | 28 | 0.24 |
| 1990 | 53 | 0.26 | 53 | 0.26 | 53 | 0.16 | 53 | 0.41 | 53 | 0.18 |
| 1991 | 66 | 0.23 | 66 | 0.23 | 66 | 0.15 | 66 | 0.39 | 66 | 0.16 |
| 1992 | 21 | 0.16 | 21 | 0.17 | 21 | 0.11 | 21 | 0.27 | 21 | 0.12 |

# LUNAR LASER RANGING

EARTH ROTATION (UT0-UTC) FROM LUNAR LASER RANGING JPL 92 M 01

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

Lunar Laser Ranging (LLR) data have been acquired and analyzed between August, 1969 and January, 1992. 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. Values of UT0-UTC through 1990 have been submitted previously; 56 such values were derived from data acquired in 1991.

The full range data set comprises 7449 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. The weighted mean uncertainty in the values of UT0-UTC for 1991 is 0.061msec. This set of values is designated EOP(JPL) 92 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 DE246/LE246. The lunar librations were integrated simultaneously with the ephemeris.

Plate motion has been applied to the station coordinates using the AM0-2 model of Minster and Jordan (1978). The base epoch for plate motion is January 1, 1991 (JD 2448257.5).

A correction to the luni-solar precession constant (Lieske *et al.*, 1977; Lieske, 1979) has been estimated as -3.0±0.4 mas/yr. The correction has been made so as not to cause a rate change in UT (Williams and Melbourne, 1982; Zhu and Mueller, 1983).

The IAU nutation (Seidelmann, 1982) has had an annual correction of 1.8 mas (taken from Herring *et al.*, 1986) applied ($\Delta\varepsilon$ = 0.0018" cos l', and $\sin\varepsilon\,\Delta\psi$ = 0.0018" sin l'). Corrections to the 9-year terms were applied from Kinoshita and Souchay (1990): $\Delta\varepsilon$ =-0.0002" cos 2Ω, and $\sin\varepsilon\,\Delta\psi$ = 0.00045" sin 2Ω; corrections to the 18.6 yr nutation coefficients were estimated, yielding

$$\Delta\varepsilon = 1.6 \cos\Omega \text{ mas}$$

$$\sin\varepsilon\,\Delta\psi = -1.4 \sin\Omega \text{ mas}$$

The constraint of the two in-phase terms (Williams *et al.*, 1991) includes a correction for the precession change, the solid-body correction of Kinoshita and Souchay (1990), and a connection between the changes of the two components. Subject to the constraint, the uncertainty in the two nutation coefficients is about 1.5mas, and the precession uncertainty is 0.4mas/yr. Without the constraint these uncertainties would be larger.

With the production of the 1991 values of UT0-UTC a set of geocentric station locations has been established. It is designated as SSC(JPL) 92 M 01 and is available on request from the Central Bureau of IERS. 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 uncertainties in each of the cylindrical coordinates for all stations are: spin radius, 4cm; longitude, 1.5mas (4 cm); and $z$, 8cm. Each of the three cylindrical coordinates of the five sites has significant correlation with the corresponding coordinate of the remaining four sites; these correlations are positive, implying that the coordinates shift together in the estimation process.

It should be noted that the McDonald 2.7m 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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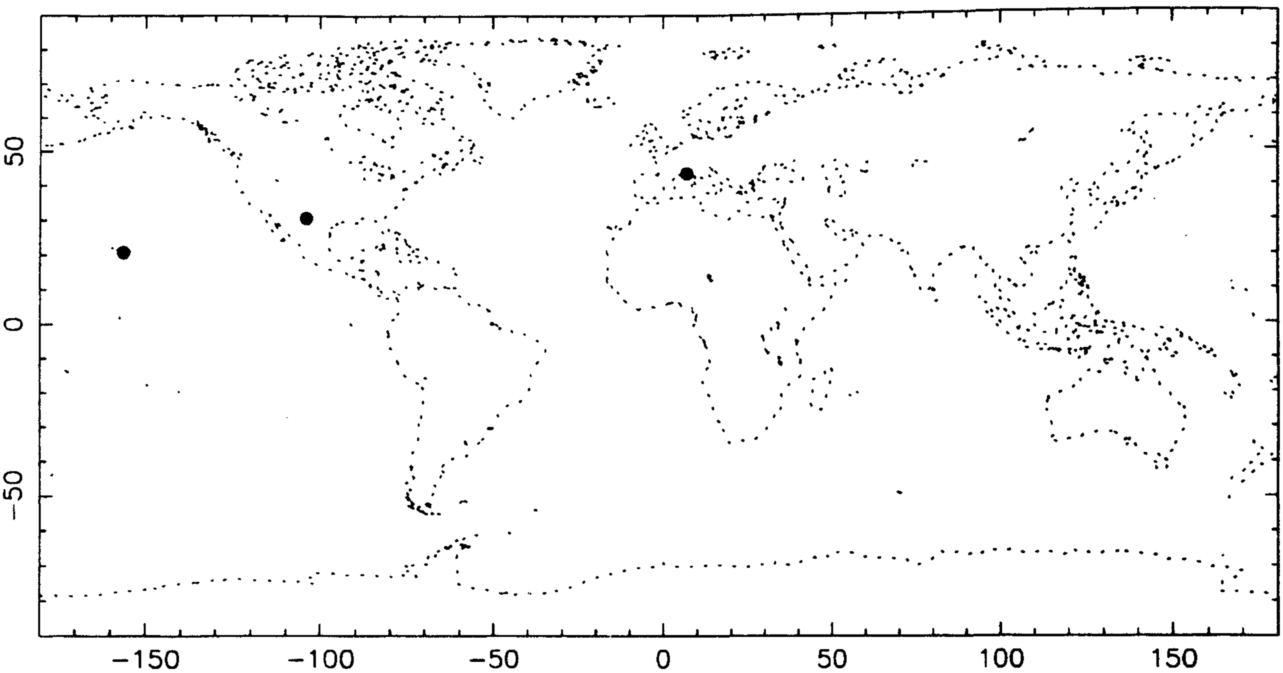
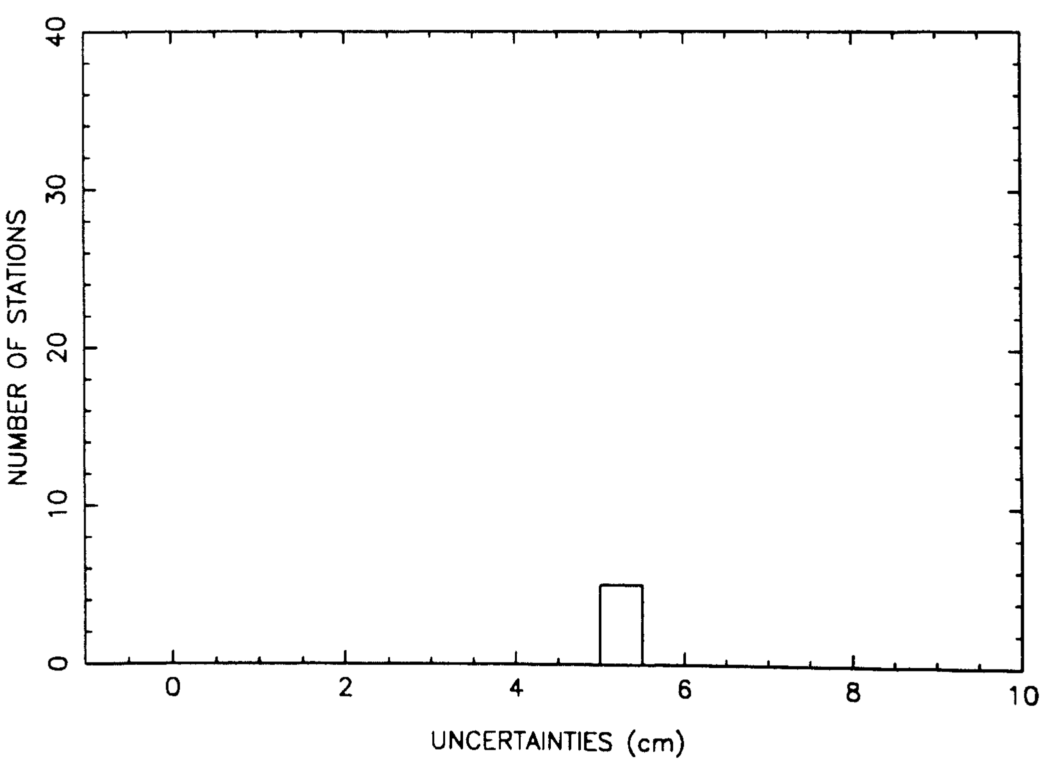
**Summary descriptions of the terrestrial system attached to the set of station coordinates SSC(JPL) 92 M 01**

| | |
|---|---|
| 1- Technique : | LLR |
| 2- Analysis center : | JPL |
| 3- Solution identifier : | SSC(JPL) 92 M 01 |
| 4- Software used : | JPL LLR software |
| 5- Relativity scale for station coordinates : | SSB |
| 6- Permanent tidal correction on stations : | No |
| 7- Tectonic plate model : | AM0-2 |
| 8- Velocity of light : | 299792458 m/sec |
| 9- Geogravitational constant (GM) : | From the ephemeris 398600441E14 (geocentric). GM does not influence the LLR station radii. |
| 10- Reference epoch : | January 1, 1991 (JD 2448257.5) |
| 11- Adjusted parameters : | Cylindrical coordinates of stations (rates fixed). The three McDonald site differences are constrained to surveys. |
| 12- Definition of the origin : | Geocenter (center of mass) |
| 13- Definition of the orientation : | Earth rotation values from 1969 to 1992 taken from a file of R. Gross consisting of SPACE91 (aligned with IERS system) extended backward with astrometric and LLR measurements. Pre 1976 variation of latitude was adjusted from LLR data during the solution for stations, orbit, precession, 18.6 yr nutations, etc. |
| 14- Constraint for time evolution : | It was necessary to solve for overall corrections to the UT1 and polar motion rates in the UT1-polar motion file. |




Distribution of the 3 sites of the terrestrial frame SSC(JPL) 92 M 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 5 stations of the terrestrial frame SSC(JPL) 92 M 01.

EOP(JPL) 92 M 01 From Apr 1970 to Jan 1992

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

| YEAR | φ | | UT0 | |
|---|---|---|---|---|
| | Nb | Sigma | Nb | Sigma |
| 1970 | 15 | 19.88 | 15 | 10.81 |
| 1971 | 35 | 18.17 | 35 | 8.56 |
| 1972 | 72 | 11.71 | 72 | 5.56 |
| 1973 | 106 | 22.72 | 106 | 8.27 |
| 1974 | 69 | 16.00 | 69 | 7.05 |
| 1975 | 87 | 14.72 | 87 | 7.56 |
| 1976 | 64 | 12.02 | 64 | 5.61 |
| 1977 | 68 | 9.35 | 68 | 4.39 |
| 1978 | 49 | 10.34 | 49 | 5.58 |
| 1979 | 66 | 8.49 | 66 | 4.63 |
| 1980 | 68 | 7.41 | 68 | 3.95 |
| 1981 | 45 | 10.30 | 45 | 4.13 |
| 1982 | 6 | 10.41 | 6 | 4.82 |
| 1983 | 0 | | 0 | |
| 1984 | 26 | 4.94 | 26 | 2.58 |
| 1985 | 111 | 6.60 | 111 | 2.66 |
| 1986 | 28 | 5.20 | 28 | 2.09 |
| 1987 | 19 | 4.44 | 19 | 1.25 |
| 1988 | 71 | 2.37 | 71 | 1.08 |
| 1989 | 42 | 2.37 | 42 | 0.98 |
| 1990 | 89 | 1.87 | 89 | 1.12 |
| 1991 | 56 | 1.55 | 56 | 0.84 |
| 992 | 7 | 1.05 | 7 | 0.49 |

DETERMINATION OF UNIVERSAL TIME BY LUNAR LASER RANGING SHA 92 M 01

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

Lunar Laser Ranging (LLR) data have been analyzed during JD 2447527.5 - JD 2448621.5. This data set contains 1693 normal points reflected from four reflectors, and was used to estimate station locations, reflector locations, lunar gravity and orbit parameters. The post-fit residuals are analyzed to obtain 201 values of UT0-UTC during this period. Due to the need of solving the normal time between first and last normal points should be greater than 1.5 hour and more than two points per day are needed. Theoretical distances from station to the retro-reflector of the moon are calculated using the IERS standards (McCarthy 1989).The influence of plate motion is taken into account with AM0-2 model of Minster and Jordan (1978). The planetary ephemeris DE303/LE303 is used for calculating the positions of the Moon and the Earth. The lunar librations integrated simultaneously with the ephemeris LE303 are adopted for calculating the lunar physical libration. The cylindrical station coordinates designated as SSC(SHA) 92 M 01 are available on request from the Central Bureau of IERS. The mathematical model is described in reference 2 (Jin *et al.* 1985). UT0 is calculated in one day interval. The precision of the normal point is taken for the weight of observational equation.

**Acknowledgments.** The planetary ephemeris DE303/LE303 is supplied by Jet Propulsion Laboratory, California Institute of Technology. The global data of lunar laser ranging are obtained from Dr.Veillet, CERGA.

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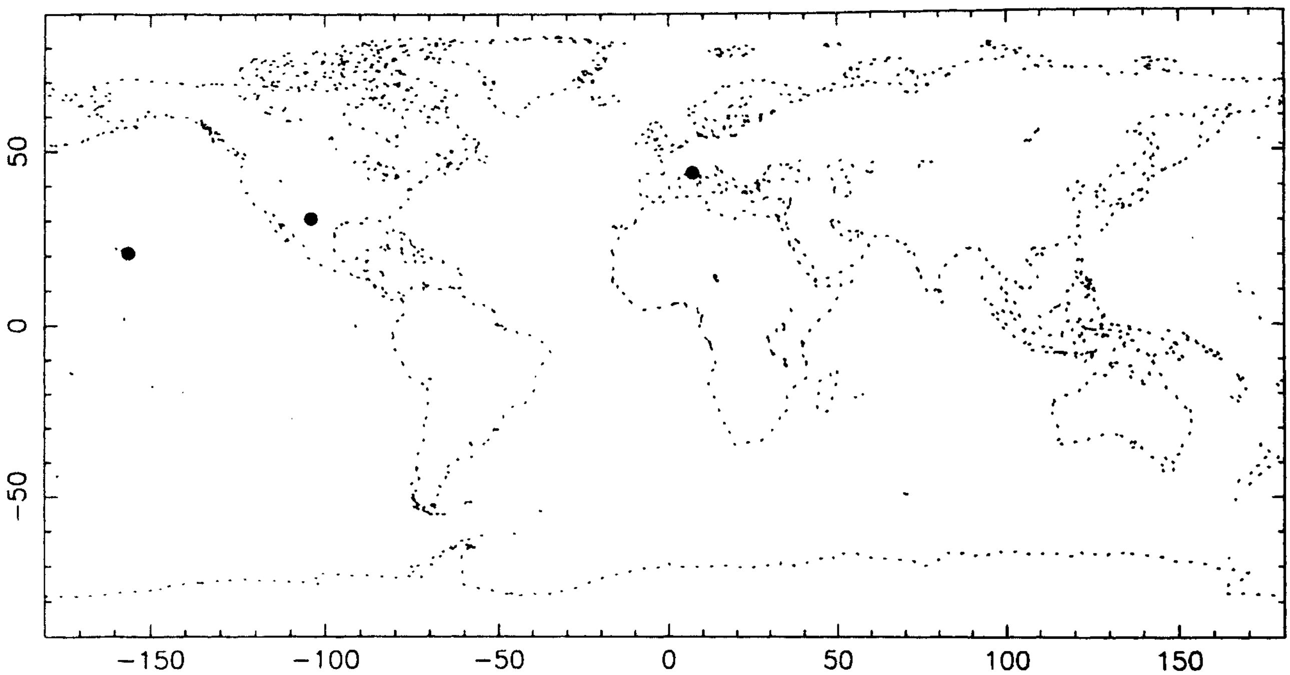


Distribution of the 3 sites of the terrestrial frame SSC(SHA) 92 M 01.

EOP(SHA) 92 M 01 From Jan 1989 to Dec 1991

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

| YEAR | UT0 | |
|---|---|---|
| | Nb | Sigma |
| 1989 | 54 | 1.60 |
| 1990 | 87 | 1.20 |
| 1991 | 52 | 1.20 |

# UT0 AND VARIATION OF LATITUDE DETERMINATION FROM LUNAR LASER RANGING OBSERVATIONS FOR 1969-1991 UTXMO 92 M 01

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

We have analyzed the total set of lunar laser ranging data available to us to determine UT0-UTC. These data were acquired between September, 1969 and March, 1992. A total of 7617 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 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 875 station/reflector pair estimations of UT0-UTC including 58 UT0 estimates, on 46 nights, in 1991. This is down significantly from the number of estimates we were able to make in 1990 due, in part, to the cessation of lunar laser ranging at Haleakala in December of 1990.

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) LGN7692. We have biased the UT1COM42/WOBCOM29 series to the LGN7692 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). A full correlation matrix for these station coordinates has 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 5.2 cm. The weighted rms of the postfit residuals for the 476 normal points obtained by the two active stations during 1991 was 2.7 cm. The number of normal points was down from last year while the rms was about 10% smaller.

We have compared our UT0 and variation of latitude series with the IRIS VLBI 5-day 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 IRIS UT1 and polar motion values. Interpolation of the IRIS 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 1992.2).

Table 1. Comparison between University of Texas McDonald Observatory LLR UT0R and variation of latitude (DPhi) and IRIS VLBI 5-day values. The period of comparison is 1986.5 to 1992.2. The epoch of the linear fit is 1989.35.

| Station | | Bias (mas) | Slope (mas/yr) | WRMS (mas) | N |
|---|---|---|---|---|---|
| CERGA | DUT0R: | -1.02±0.15 | -1.02±0.11 | 2.04 | 214 |
| | DPhi: | -5.99±0.16 | 0.35±0.11 | 1.84 | |
| MLRS | DUT0R: | 8.46±4.29 | 1.20±2.02 | 1.66 | 7 |
| (Saddle) | DPhi: | 18.06±8.65 | 8.12±4.24 | 5.10 | |
| MLRS | DUT0R: | 2.44±0.72 | -0.76±0.43 | 1.91 | 19 |
| (Mt. Fowlkes) | DPhi: | 0.73±0.82 | 1.49±0.52 | 3.50 | |
| Maui | DUT0R: | 1.02±0.33 | -1.13±0.21 | 2.80 | 80 |
| | DPhi: | 5.57±0.47 | 0.69±0.31 | 6.14 | |

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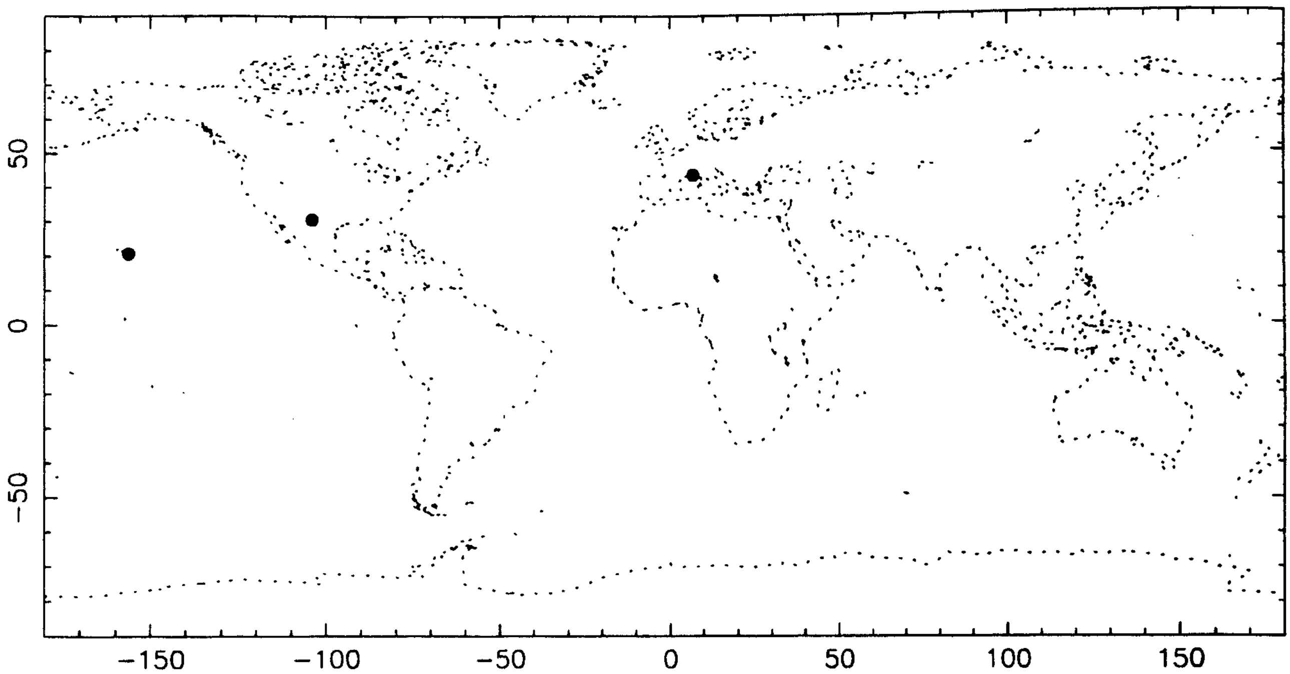
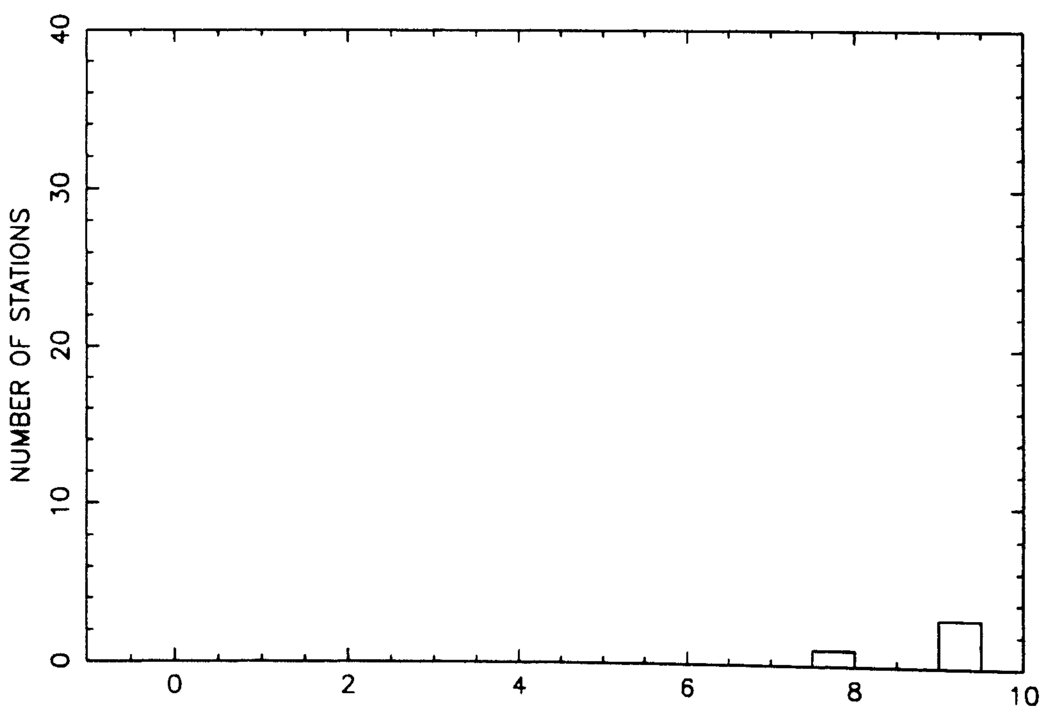
**Summary description of the terrestrial system attached to the set of station coordinates SSC(UTXMO) 92 M 01**

| | |
|---|---|
| 1 - Technique : | LLR |
| 2 - Analysis Center : | UT/McD |
| 3 - Solution identifier : | UTXMO 92 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 : | 299792458 |
| 9 - Geogravitational constant (GM) : | 3.98600449e14 |
| 10 - Reference epoch : | 1984.0 |
| 11 - Adjusted parameters : | $\lambda$, $\varphi$, h |
| 12 - Definition of the origin : | Geocenter |
| 13 - Definition of the orientation : | Fixed to CSR LGN7692 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) 92 M 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 4 stations of the terrestrial frame SSC(UTXMO) 92 M 01. 1 station with uncertainty larger than 10 cm is not shown.

EOP(UTXMO) 92 M 02 From Oct 1970 to Jun 1992

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

| YEAR | UT0 | |
|---|---|---|
| | Nb | Sigma |
| 1970 | 5 | 6.60 |
| 1971 | 11 | 5.40 |
| 1972 | 48 | 5.60 |
| 1973 | 56 | 5.50 |
| 1974 | 28 | 4.60 |
| 1975 | 41 | 5.50 |
| 1976 | 41 | 5.20 |
| 1977 | 29 | 4.40 |
| 1978 | 22 | 4.70 |
| 1979 | 27 | 4.40 |
| 1980 | 33 | 3.90 |
| 1981 | 3 | 4.20 |
| 1982 | 0 | |
| 1983 | 7 | 4.00 |
| 1984 | 44 | 4.10 |
| 1985 | 109 | 4.00 |
| 1986 | 27 | 3.40 |
| 1987 | 29 | 3.60 |
| 1988 | 56 | 2.65 |
| 1989 | 49 | 2.90 |
| 1990 | 90 | 2.60 |
| 1991 | 59 | 2.60 |
| 1992 | 22 | 2.10 |

# GLOBAL POSITIONING SYSTEM

GPS STATION COORDINATES FROM THE GIG'91 EXPERIMENT : JPL 91 P 01
JPL 91 P 02

Geoffrey Blewitt, Michael B. Heflin, Ulf J. Lindqwister, Rajendra P. Malla and Frank H. Webb
Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA91109, USA - E-mail: GEOFF@LOGOS.JPL.NASA.GOV (or to MBH at same address)

The following solutions were derived from 21 globally distributed Rogue receivers operating from January 22 - February 12 1991 in the GIG'91 experiment.

**Summary description of the terrestrial system attached to the set of station coordinates SSC(JPL) 91 P 01:**

| | |
|---|---|
| 1- Technique : | GPS |
| 2- Analysis Center : | JPL |
| 3- Solution identifier : | SSC(JPL) 91 P 01 |
| 4- Software used : | GIPSY |
| 5- Relativity scale : | Local Earth |
| 6- Permanent tide correction on station : | No |
| 7- Tectonic plate model : | None (single epoch solution) |
| 8- Velocity of light : | 299792458 m/sec |
| 9- GM : | 3.98600440*10**14 m**3 s**-2 |
| 10- Reference epoch : | 1991.1 |
| 11- Adjusted parameters : | Station X, Y, Z at 1991.1<br>PMX, PMY every 24 hours;<br>GPS epoch state and 3 solar radiation biases every 24 hours;<br>Random walk zenith tropospheres;<br>White noise clocks (Goldstone H-maser is the reference clock);<br>Carrier phase ambiguities as real valued (not bias-fixed) |
| 12- Definition of origin : | GEM T2 (truncated to 12 x 12)<br>with C10 = C11 = S11 = 0 |
| 13- Definition of orientation : | Loose a priori constraints on all GPS epoch states, station coordinates and polar motion from Bulletin-B forces crude alignment with ITRF to within several meters. |
| 14- Constraint for time-evolution : | No time evolution. |

**Summary description of the terrestrial system attached to the set of station coordinates SSC(JPL) 91 P 02:**

| | |
|---|---|
| 1- Technique: | GPS |
| 2- Analysis Center: | JPL |
| 3- Solution identifier: | SSC(JPL) 91 P 02 |
| 4- Software used: | GIPSY |
| 5- Relativity scale: | Local Earth;<br>Scale JPL91G01 solution to ITRF'90 (mapped to 1991.1 using site velocities from GLB718, except for KOSG for which we used SSC(IERS)90L02) |
| 6- Permanent tide correction on station: | No |
| 7- Tectonic plate model: | None (single epoch solution) |
| 8- Velocity of light: | 299792458 m/sec |
| 9- GM: | 3.98600440*10**14 m**3 s**-2 |
| 10- Reference epoch: | 1991.1 |
| 11- Adjusted parameters: | Station X, Y, Z at 1991.1;<br>PMX, PMY every 24 hours;<br>GPS epoch state and 3 solar radiation biases every 24 hours;<br>Random walk zenith tropospheres;<br>White noise clocks (Goldstone H-maser is the reference clock);<br>Carrier phase ambiguities as real valued (not bias-fixed) |
| 12- Definition of origin: | Apply translation of JPL 91 P 01 into ITRF'90 (mapped to 1991.1) |
| 13- Definition of orientation: | Apply rotation of JPL 91 P 01 into ITRF'90 (mapped to 1991.1) |
| 14- Constraint for time-evolution: | No time evolution. |

Table 1. TRANSFORMATION BETWEEN SSC(JPL) 91 P 01 AND ITRF90 (MAPPED TO 1991.1)

| PARAMETER | ESTIMATE | |
|---|---|---|
| Translation in X | -0.100 +- 0.013 | (m) |
| Translation in Y | 0.134 +- 0.016 | (m) |
| Translation in Z | -0.134 +- 0.012 | (m) |
| Scale | -3.459 +- 1.402 | (10**-9) |
| Rotation about X | 3.592 +- 3.445 | (10**-9 radians) |
| Rotation about Y | -2.672 +- 3.445 | (10**-9 radians) |
| Rotation about Z | -302.006 +- 1.794 | (10**-9 radians) |

Normalized Chi-square 0.967

Notes:
(1) Only sites with available ties could be used.
(2) YELL was not used due to a relatively large formal error in ITRF'90.
(3) Transformation is a least-squares weighted fit using only diagonal covariance elements. Error in propagating ITRF'90 from 1988.0 to 1991 was assumed to be negligible. Input GPS error bars have been defined such that normalized chi-square of this fit is close to 1.
(4) Transformation parameters are as defined by IERS, with the following sign convention:
(GPS-ITRF) = TRANFORMATION * ITRF

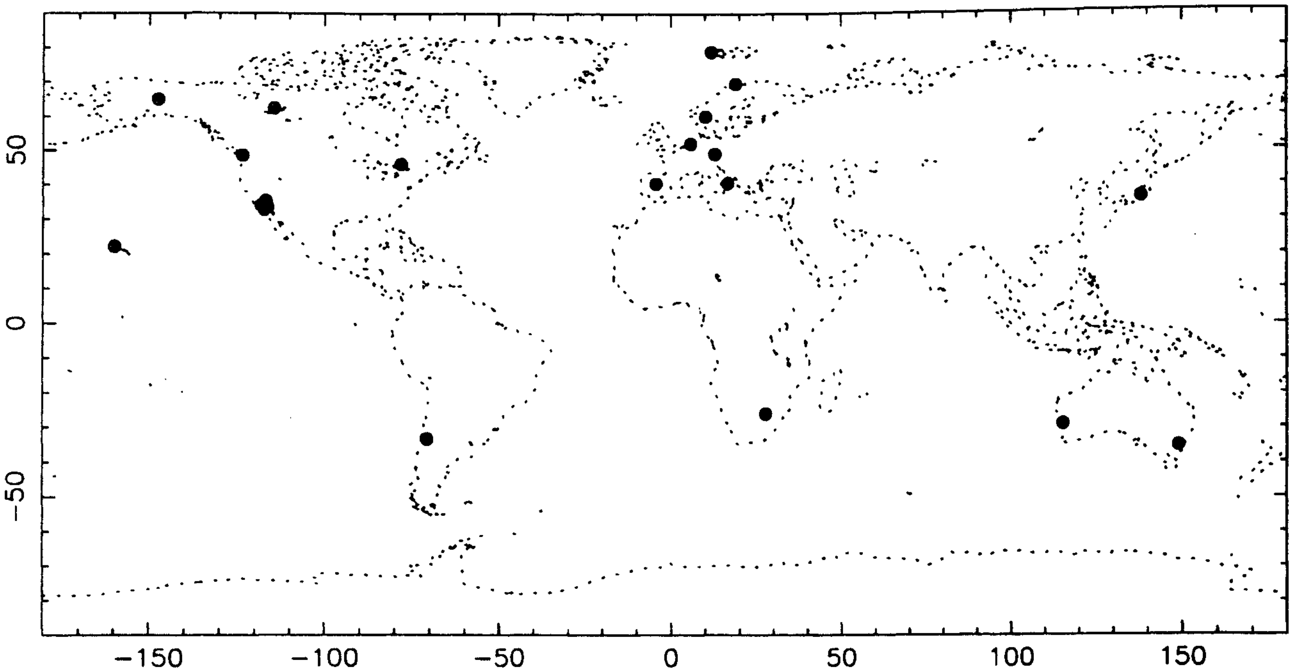
Table 2. COORDINATE RESIDUALS: SSC(JPL) 91 P 02 - ITRF90 (MAPPED TO 1991.1)

| | RESIDUAL (CM) | | | FORMAL ERROR (CM) | | | RESIDUAL (LOCAL COORDS) | | |
|---|---|---|---|---|---|---|---|---|---|
| SITE | X | Y | Z | SX | SY | SZ | E | N | V |
| ALGO | -1.9 | 2.4 | -.3 | 1.2 | 1.1 | 1.1 | -1.3 | 1.8 | -2.1 |
| JPLM | 2.1 | .1 | -1.5 | 1.6 | 1.9 | 1.7 | 1.8 | -.6 | -1.8 |
| KOKB | -.5 | -.8 | -.3 | .7 | 1.4 | .9 | .6 | -.6 | .6 |
| KOSG | 1.5 | -1.7 | 2.0 | 1.9 | 2.2 | 1.9 | -1.9 | .2 | 2.4 |
| PINY | -.5 | -2.3 | 1.2 | 1.5 | 1.6 | 1.6 | .6 | -.3 | 2.5 |
| TROM | 1.5 | -.6 | 1.6 | 1.7 | 1.5 | 2.2 | -1.0 | -.6 | 1.9 |
| WETB | .0 | -.1 | -1.2 | 1.1 | 1.3 | 1.2 | -.1 | -.8 | -.9 |

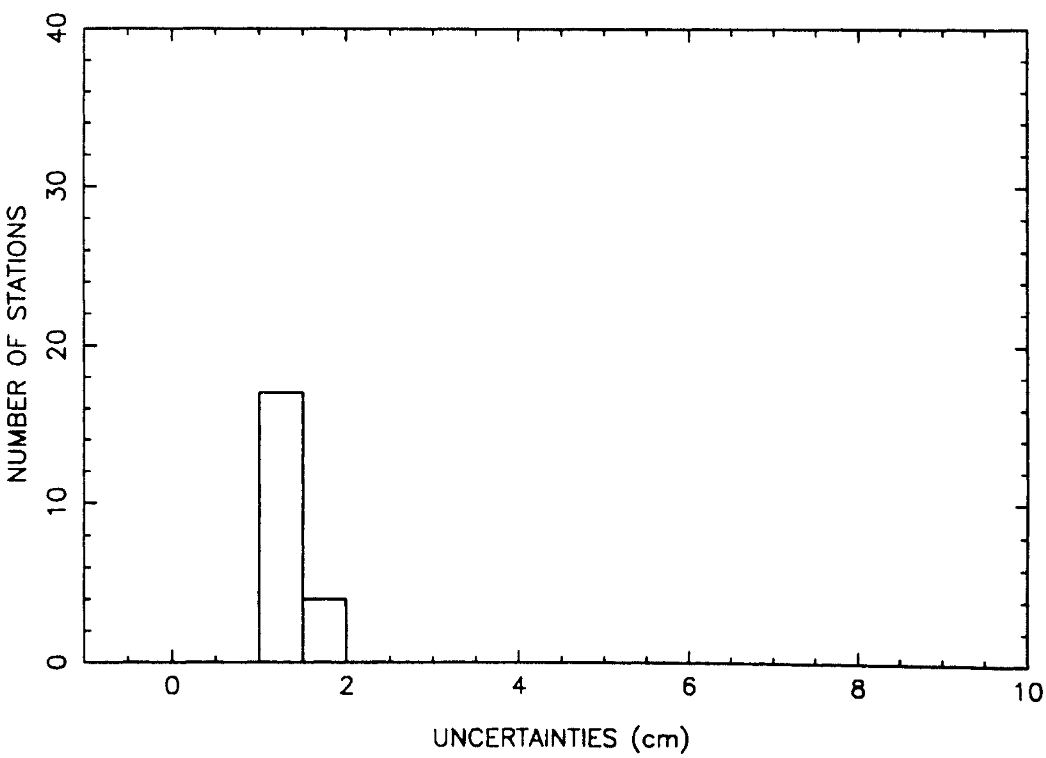
Weighted RMS for X coordinate ( 4.67 DOF) = 1.4 cm
Weighted RMS for Y coordinate ( 4.67 DOF) = 1.6 cm
Weighted RMS for Z coordinate ( 4.67 DOF) = 1.2 cm
Weighted RMS for all (14.00 DOF) = 1.4 cm

Unweighted RMS for E coordinate ( 4.67 DOF) = 1.5 cm
Unweighted RMS for N coordinate ( 4.67 DOF) = 1.0 cm
Unweighted RMS for V coordinate ( 4.67 DOF) = 2.3 cm
Unweighted RMS for all (14.00 DOF) = 1.7 cm

Notes:
(1) Quoted RMS values correctly account for number of degrees of freedom (DOF).
(2) Formal error is computed in the weighted least-squares process, where input data were (GPS-ITRF) coordinates with GPS+ITRF error added in quadrature.
(2) Total weighted RMS is smaller than unweighted RMS, indicating that it is better to use weights rather than use none at all.
(3) Clearly, the vertical component is not as well determined; however, this information was not incorporated into weights (since we used diagonal weight matrix in cartesian system). This is why RMS for local coordinates are only quoted as "unweighted RMS".




Distribution of the 21 sites of the terrestrial frame SSC(JPL) 92 P 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 21 stations of the terrestrial frame SSC(JPL) 92 P 01.

POLAR MOTION AND UT1 TIME SERIES DERIVED FROM GPS OBSERVATIONS
JPL 91 P 03

U. J. Lindqwister, S. M. Lichten, G. Blewitt, and A. P. Freedman, MS: 238-625,
Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109

Daily estimates of UT1 and polar motion parameters x (PMX) and y (PMY) have been obtained with measurements from a worldwide network of Global Positioning System (GPS) receivers, obtained during the three week GIG'91 experiment in January-February, 1991 (Lichten *et al.*, 1992; Herring *et al.*, 1991; Lindqwister *et al.*, 1992). The GIG'91 experiment was carried out between January 22 and February 13, 1991 by numerous international agencies and utilized over 120 GPS receivers (Melbourne *et al.*, 1992). A subset of 21 globally distributed Rogue GPS receivers was chosen for this study. For a complete list of station names and locations see Heflin *et al.* (1991).

The data analysis was carried out at JPL using the GIPSY orbit determination and baseline estimation software package. Single day solutions were obtained using a factorized Kalman-type filter (Bierman, 1977). Station positions; initial satellite positions, velocities, and solar radiation pressure coefficients; and carrier phase ambiguities were all estimated daily as constant parameters, with the exception of the coordinates of the fiducial stations, which were not estimated at all. The wet zenith tropospheric delay was estimated as a random walk stochastic with a process noise constraint of 0.17 mm/sec**-0.5 corresponding to a 5 cm variation over a day of the tropospheric parameter at zenith. The Lanyi mapping function was used to obtain delays at all observed elevation angles down to the 15 degree elevation cutoff (Lanyi, 1984). All station and satellite clocks were solved for using a white noise stochastic model, with the exception of the clock at Goldstone, which was used as a reference. For more details on the parameter estimation strategies routinely used by GIPSY to reduce GPS data see Lichten and Border (1987).

For the Polar Motion analysis three stations at Goldstone (USA), Tromso (Norway), and Wettzell (Germany) were held fixed in the SV5 reference frame (Murray *et al.*, 1990), which is a combined VLBI and SLR solution from 1990 computed at epoch 1991.1. The coordinates used for the three fiducial sites are available on request from the Central Bureau of IERS. The offset of the Earth's center of mass from the origin of the SV5 reference frame (the geocenter offset) was assumed to be zero. All the Earth orientation parameters (EOP) are hence computed in the SV5 reference frame. The origin and scale are defined within SV5 by the CSR8902 SLR adjustement (Schutz *et al.*, 1989) and the orientation is consistent with the IERS ITRF89 reference frame (to a few ppb), and the fiducial station coordinates are derived from the GLB659 VLBI solution (Caprette *et al.*, 1990). For more details on the SV5 solution, contact Mark Murray, MIT. The Polar Motion parameters were estimated as daily constants and the tabulated values represent 24-hour averages computed at noon UTC every day, spanning 3 weeks starting on January 22, 1991 (with the exception of January 31). The UT1 parameter was held fixed at nominal values published in IERS Bulletins B37 and B38 (1991).

The UT1 estimates were determined in separate filter solutions with Goldstone and Kootwijk held fixed as fiducials to coordinates from SV5. In addition, the Polar Motion parameters were held fixed at nominal values from Bulletins B37 and B38 (1991). The UT1 solutions were obtained simultaneously with estimates for the geocenter. UT1 was estimated from GPS data in three segments spanning the 3-week experiment: every 24 hrs (at midnight each day), new GPS orbit parameters were introduced and initially, every 12 hrs, UT1 estimates were output with a white noise reset being applied to UT1 each day at 12:00 noon. Because of the 24-hr smoothing applied to the GPS data, the original 12-hr estimates were averaged to produce new UT1 estimates once per day (at noon). These are listed along with formal errors, which are at the level of 0.01-0.02 msec. Since data from several days are not included in the table, the UT1 time series is restarted on Feb. 1 and Feb. 6.

Each of the three continuous segments of UT1 estimates are self-consistent, but between them there is an arbitrary bias which cannot be determined from GPS data alone. We have calibrated this bias simply by aligning the GPS estimates for each segment with the KEOF (VLBI/SLR) estimates for the corresponding time interval in a mean sense. See Morabito *et al.* (1988) and Gross and Steppe (1992) for a discussion on the KEOF combined VLBI- and SLR-network solutions for Earth orientation. Thus the GPS estimates provide a precise record of change in UT1 from time point to time point (where the data are continuous), but they may contain an arbitrary bias in UT common to all points in each segment.

Note that the use of slightly different fiducials when deriving Polar Motion and UT1 still fix each solution to the SV5 frame with at most a small bias (cm-level) between solutions. At the time of the analysis the ground tie at Goldstone was not known. Instead coordinates from a previous solution was used and then rotated into the SV5 frame using a seven parameter transformation. Moreover the estimation of the geocenter in the UT1 solutions should be of little consequence relative to the Polar Motion solutions (except for the possibility of introducing a bias to one or the other of the series).

The errors quoted are the 1-sigma formal errors obtained directly from the filter and hence should be considered a lower limit for the true errors in the series. Comparisons with similar polar motion series from VLBI and SLR have shown rms agreement at the level of 0.3-0.5 mas for the three week period covered by the experiment (Lindqwister *et al.*, 1992). Note that the error bars ranges from 0.2-0.4 mas, hence even though the error bars are minimal they are not likely to be far from the true errors. The UT1 formal errors are at the level of 0.01-0.02 msec. Comparisons with VLBI solutions for UT1 for this time period show rms agreement at the level of 0.04 ms (Lichten *et al.*, 1992).

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**Summary Description of the terrestrial system for solution EOP(JPL) 91 P 03:**

| | |
|---|---|
| 1- Technique : | GPS |
| 2- Analysis Center : | JPL |
| 3- Solution identifier : | EOP(JPL) 91 P 01 |
| 4- Software used : | GIPSY |
| 5- Relativity scale : | Local Earth |
| 6- Permanent tide correction on station : | No |
| 7- Tectonic plate model : | None (single epoch solution) |
| 8- Velocity of light : | 299792458 m/sec |
| 9- GM : | 3.98600440*10**14 m**3 s**-2 |
| 10- Reference epoch : | 1991.1 |
| 11- Adjusted parameters : | Station X, Y, Z at 1991.1;<br>PMX, PMY every 24 hours;<br>GPS epoch state and 3 solar radiation biases every 24 hours;<br>Random walk zenith tropospheres;<br>White noise clocks (Goldstone H-maser is the reference clock);<br>Carrier phase ambiguities as real valued (not bias-fixed) |
| 12- Definition of origin : | Defined through SV5. |
| 13- Definition of orientation : | Defined through SV5. |
| 14- Constraint for time-evolution : | No time evolution. |

EOP(JPL) 91 P 03 From Jan 1991 to Feb 1991

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 |
| 1991 | 22 | 0.25 | 22 | 0.30 | 20 | 0.10 |

# SATELLITE LASER RANGING

# EARTH ORIENTATION AND SITE COORDINATES FROM THE CENTER FOR SPACE RESEARCH SOLUTION CSR 92 L 01

R. J. Eanes and M. M. Watkins, Center for Space Research, University of Texas at Austin, Austin TX 78712

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 used for July 1991 through December 1991. A summary of the 1991 data used in the solution is provided in Table 1. The column titled RBTB RMS refers to the root mean square of the residuals after removing an estimated range bias and time bias. The column titled PREC EST refers to the residual rms after removing a second order polynomial, yielding an estimate of the internal precision of the data.

Mean positions for all sites were adjusted and horizontal site velocities were adjusted for 42 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 mean gravity field was TEG-2, a state of the art gravity field computed at the University of Texas 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.
3) The solid tide model has been expanded to include third degree and fourth degree terms.
4) The geogravitational constant, GM, was 398600.4415 km3/s2.
5) The nominal plate motion model was NUVEL-1 NNR.
6) The free core nutation period has been changed from 460 to 430 days.

The data was weighted in a piecewise continuous, linearly interpolated model to reflect the improvement in laser hardware over the data span. The weighting curve had the following node points:

MJD 42905.0 : 700 mm
MJD 44162.0 : 400 mm
MJD 45578.0 : 200 mm
MJD 47000.0 : 100 mm

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 13 February 1992, a period of 15.8 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. Thus if the solution for a given 3 day interval yielded unacceptably large uncertainties on the adjusted parameters, the interval was extended by another 3 day interval 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 SPACE91 series at periods longer than about 60 days (Gross, 1992).

## References

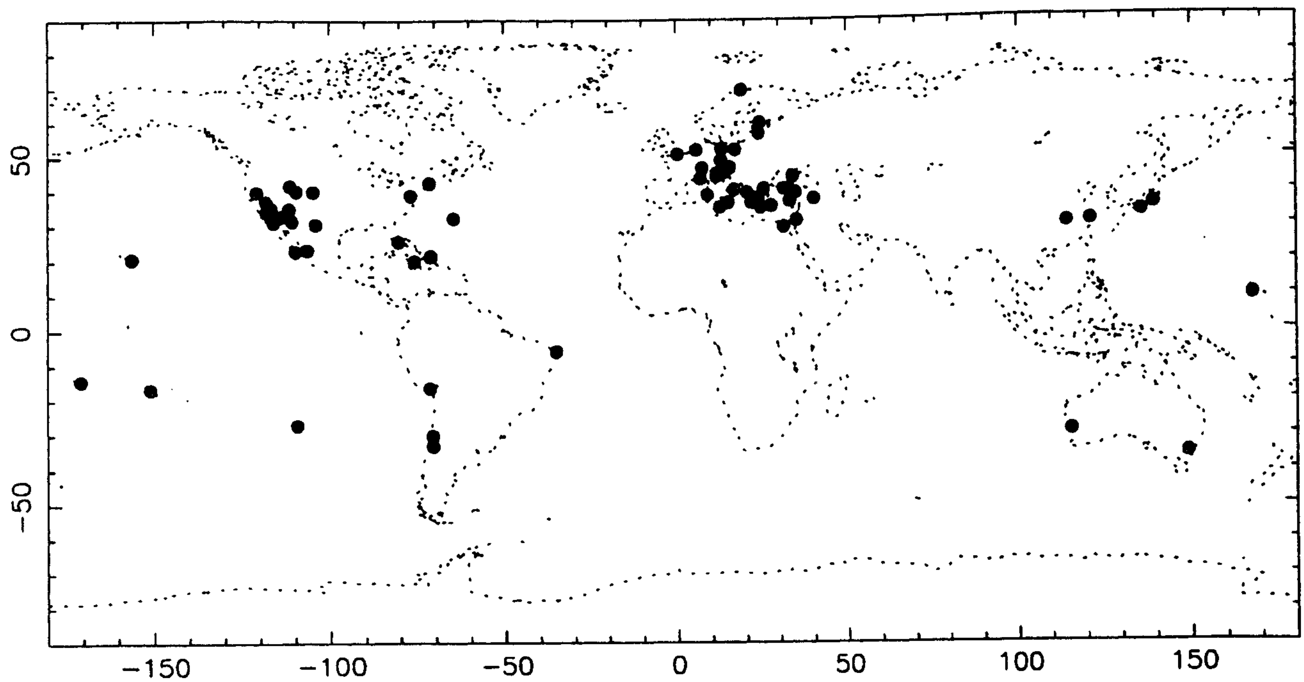
Gross, R.S., 1992: A Combination of Earth Orientation Data: SPACE91, *IERS Technical Note 11*, Observatoire de Paris, p. 113.

Table 1. Summary of 1991 Lageos Residual Analysis, B Ver NP Jan-Jun, QL Jul-Dec

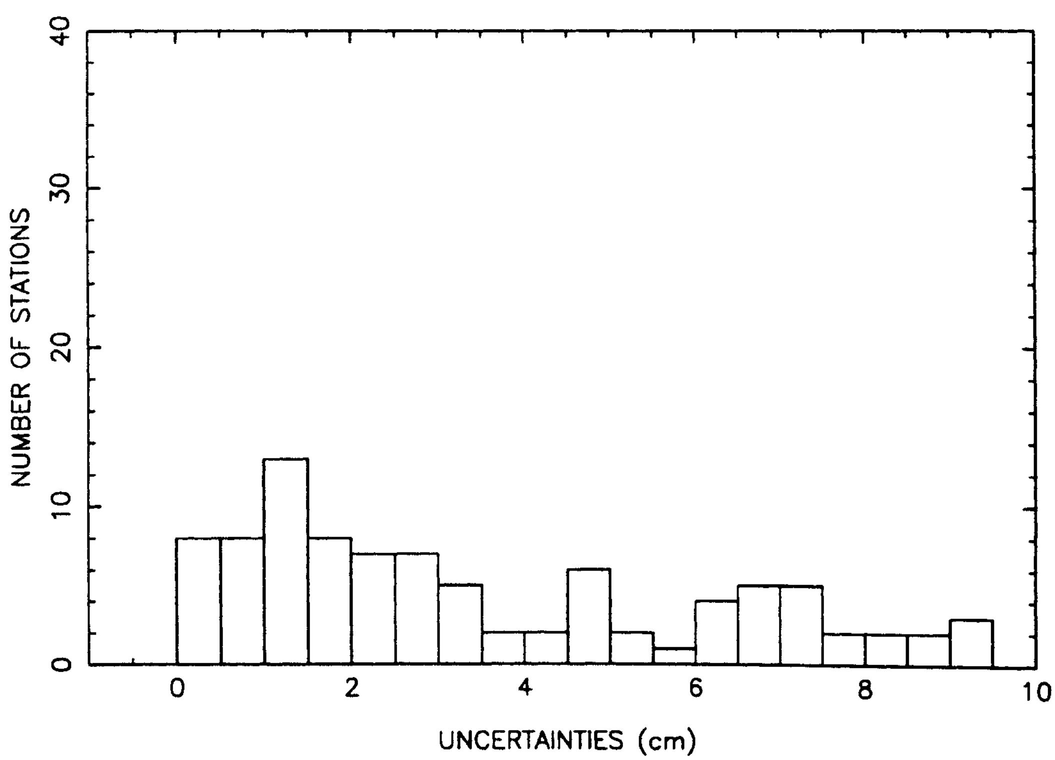
| Station | # of Passes | # of 2-min np | number edited | percent edited | number kept | Raw RMS (cm) | RBTB RMS (cm) | PREC. EST. (cm) |
|---|---|---|---|---|---|---|---|---|
| 1181 POTSDM | 29 | 246 | 71 | 28.9 | 175 | 9.4 | 6.0 | 4.7 |
| 1873 SIMEIZ | 27 | 193 | 27 | 14.0 | 166 | 8.6 | 5.4 | 3.9 |
| 1884 RIGA | 58 | 627 | 88 | 14.0 | 539 | 8.6 | 3.8 | 3.4 |
| 1953 SANCUB | 27 | 184 | 105 | 57.1 | 79 | 9.9 | 6.1 | 5.3 |
| 7046 BRLAK2 | 60 | 844 | 10 | 1.2 | 834 | 2.3 | 0.6 | 0.5 |
| 7080 MCDON4 | 217 | 2403 | 32 | 1.3 | 2371 | 2.5 | 0.8 | 0.6 |
| 7090 YARAG | 226 | 3875 | 54 | 1.4 | 3821 | 2.7 | 0.3 | 0.2 |
| 7097 EASTR2 | 43 | 512 | 1 | 0.2 | 511 | 3.1 | 1.1 | 1.0 |
| 7105 GRF105 | 175 | 2393 | 31 | 1.3 | 2362 | 2.5 | 0.5 | 0.4 |
| 7109 QUINC2 | 145 | 1754 | 23 | 1.3 | 1731 | 2.6 | 0.5 | 0.4 |
| 7110 MNPEAK | 337 | 4932 | 52 | 1.1 | 4880 | 2.9 | 0.4 | 0.2 |
| 7112 PLATVL | 28 | 345 | 6 | 1.7 | 339 | 4.2 | 0.8 | 0.7 |
| 7122 MAZTLN | 70 | 1078 | 6 | 0.6 | 1072 | 2.4 | 0.4 | 0.2 |
| 7123 HUAHI2 | 48 | 558 | 8 | 1.4 | 550 | 3.6 | 1.2 | 1.1 |
| 7210 HOLLAS | 288 | 4081 | 56 | 1.4 | 4025 | 2.9 | 1.0 | 0.7 |
| 7236 WUHAN | 48 | 546 | 8 | 1.5 | 538 | 7.4 | 3.2 | 2.2 |
| 7288 MOJAV2 | 21 | 355 | 10 | 2.8 | 345 | 4.2 | 0.4 | 0.3 |
| 7295 RICHMO | 53 | 777 | 18 | 2.3 | 759 | 4.2 | 0.6 | 0.5 |
| 7401 CERTOL | 68 | 1019 | 12 | 1.2 | 1007 | 2.7 | 0.6 | 0.3 |
| 7403 ARELA2 | 126 | 1579 | 23 | 1.5 | 1556 | 3.4 | 0.9 | 0.7 |
| 7542 MONVEN | 63 | 484 | 17 | 3.5 | 467 | 4.6 | 1.6 | 1.4 |
| 7560 RIGA2 | 12 | 84 | 1 | 1.2 | 83 | 2.5 | 1.0 | 0.8 |
| 7561 SIMEI2 | 34 | 493 | 6 | 1.2 | 487 | 3.7 | 0.6 | 0.5 |
| 7597 WET597 | 12 | 117 | 1 | 0.9 | 116 | 5.0 | 0.9 | 0.5 |
| 7810 ZIMMER | 140 | 1835 | 11 | 0.6 | 1824 | 4.1 | 2.2 | 2.0 |
| 7811 BOROWC | 12 | 71 | 5 | 7.0 | 66 | 7.7 | 4.0 | 3.6 |
| 7831 HELWAN | 118 | 1167 | 5 | 0.4 | 1162 | 4.3 | 2.4 | 2.0 |
| 7834 WETZEL | 17 | 187 | 4 | 2.1 | 183 | 2.7 | 1.2 | 1.1 |
| 7835 GRASSE | 414 | 5762 | 100 | 1.7 | 5662 | 3.8 | 1.4 | 1.0 |
| 7837 SHAHAI | 105 | 1053 | 123 | 11.7 | 930 | 8.0 | 4.3 | 3.6 |
| 7838 SHO | 77 | 1081 | 21 | 1.9 | 1060 | 5.3 | 2.8 | 2.1 |
| 7839 GRAZ | 153 | 2377 | 12 | 0.5 | 2365 | 2.8 | 0.7 | 0.5 |
| 7840 RGO | 450 | 5201 | 38 | 0.7 | 5163 | 2.6 | 0.9 | 0.7 |
| 7843 ORRLLR | 38 | 458 | 5 | 1.1 | 453 | 4.1 | 1.3 | 1.0 |
| 7883 ENSENA | 25 | 360 | 4 | 1.1 | 356 | 3.2 | 0.7 | 0.6 |
| 7907 ARELAS | 24 | 293 | 60 | 20.5 | 233 | 8.3 | 6.4 | 5.8 |
| 7918 GRF918 | 4 | 47 | 0 | 0.0 | 47 | 1.7 | 0.8 | 0.8 |
| 7920 GRF920 | 4 | 49 | 0 | 0.0 | 49 | 2.6 | 0.9 | 0.8 |
| 7939 MATERA | 163 | 2004 | 102 | 5.1 | 1902 | 6.6 | 4.8 | 4.2 |
| 8834 WETZL2 | 307 | 3155 | 92 | 2.9 | 3063 | 5.1 | 1.5 | 1.2 |

**Summary description of the terrestrial system attached to the set of station coordinates SSC(CSR) 92 L 01**

| | |
|---|---|
| 1 - Technique : | SLR |
| 2 - Analysis Center : | CSR |
| 3 - Solution Identifier : | SSC(CSR) 92 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 : | 299792458 m/sec |
| 9 - Geogravitational constant (GM) : | 398600.4415 km3/s2 |
| 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 42 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 SPACE91) solved at same intervals as orbit |
| 12 - Definition of the origin : | Geocentric, C10 = C11 = S11 = 0.0 |
| 13 - Definition of the orientation : | System oriented to agree with IERS combined in a mean sense over period 1984-1990, 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 covariance of 100 mm/yr for 41 other sites with sufficient data. |




Distribution of the 68 sites of the terrestrial frame SSC(CSR) 92 L 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 110 stations of the terrestrial frame SSC(CSR) 92 L 01. 18 stations with uncertainties larger than 10 cm are not shown.

EOP(CSR) 92 L 01 From May 1976 to Dec 1991

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 | 11.30 | 33 | 11.03 | 33 | 6.55 |
| 1977 | 82 | 11.29 | 82 | 9.53 | 82 | 6.22 |
| 1978 | 77 | 10.44 | 77 | 7.81 | 77 | 5.85 |
| 1979 | 82 | 8.07 | 82 | 7.53 | 82 | 4.88 |
| 1980 | 118 | 4.74 | 118 | 3.07 | 118 | 2.59 |
| 1981 | 112 | 4.70 | 112 | 2.86 | 112 | 2.32 |
| 1982 | 114 | 3.26 | 114 | 2.64 | 114 | 2.05 |
| 1983 | 118 | 2.49 | 118 | 2.57 | 118 | 1.48 |
| 1984 | 121 | 1.16 | 121 | 1.06 | 121 | 0.90 |
| 1985 | 121 | 0.99 | 121 | 0.85 | 121 | 0.70 |
| 1986 | 122 | 0.85 | 122 | 0.78 | 122 | 0.67 |
| 1987 | 122 | 0.58 | 122 | 0.55 | 122 | 0.45 |
| 1988 | 122 | 0.48 | 122 | 0.51 | 122 | 0.39 |
| 1989 | 121 | 0.52 | 121 | 0.51 | 121 | 0.42 |
| 1990 | 122 | 0.48 | 122 | 0.52 | 122 | 0.39 |
| 1991 | 122 | 0.61 | 122 | 0.62 | 122 | 0.46 |

# EARTH ORIENTATION AT 1-DAY INTERVALS FROM THE CENTER FOR SPACE RESEARCH CSR 92 L 02

R. J. Eanes and M. M. Watkins
Center for Space Research, University of Texas at Austin, Austin TX 78712

Solutions for orbital elements and Earth orientation parameters were computed using residuals from a long arc fit to Lagoes SLR data from November 1987 through January 1992, a period of just over 5 years. Observation equations for Earth orientation parameters and orbital elements were produced from the data during 1-day intervals centered on midnight UT. This information was combined with UT1 estimates from the JPL SPACE91 (Gross 1992) series in a Kalman smoother to produce the reported series. The forward and backward filters used in the smoother had 18 states consisting of 6 orbital parameters with their 6 excitations and 3 Earth orientation parameters with their 3 excitations.

The 9 excitation parameters were modelled as first order Gauss-Markov processes with specified time constants and steady-state variances. The EOP excitation parameters correspond to Chi1 and Chi2 for wobble and LOD for UT1. The colored noise process for Chi1 and Chi2 used 3 days for the time constant and 50 milliarcsec for the steady-state standard deviation. A full discussion of the model used for the orbital parameters is beyond the scope of this brief summary. The most important aspect of the orbit model for this report is that the stochastic process for the excitation of the longitude of the ascending node used a time constant of 3 days and a steady-state standard deviation of 200 milliarcsec per year. Use of this process noise model results in UT1 estimates that are highly correlated with the UT1 observations from the SPACE91 series, even down to periods of less than 10 days.

The terrestrial reference frame used for this solution was fixed to that of the CSR 92 L 01 series (Eanes and Watkins 1992).

## References

Gross, R.S., 1992: A Combination of Earth Orientation Data: SPACE91, *IERS Technical Note 11*, Observatoire de Paris, p. 113.

Eanes, R.J., Watkins, M.M.,1992: Earth Orientation and Site Coordinates from the Center for Space Research Solution CSR 92 L 01, *IERS Technical Note 11*, Observatoire de Paris, p. 75.

EOP(CSR) 92 L 02 From Jan 1987 to Jan 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 |
| 1987 | 365 | 0.48 | 365 | 0.45 | 365 | 0.14 |
| 1988 | 366 | 0.42 | 366 | 0.44 | 366 | 0.14 |
| 1989 | 365 | 0.45 | 365 | 0.43 | 365 | 0.13 |
| 1990 | 365 | 0.42 | 365 | 0.44 | 365 | 0.13 |
| 1991 | 365 | 0.49 | 365 | 0.49 | 365 | 0.15 |
| 1992 | 1 | 0.64 | 1 | 0.65 | 1 | 0.15 |

# EARTH ORIENTATION AND STATION COORDINATES COMPUTED FROM 11.75 YEARS OF LAGEOS OBSERVATIONS DGFII 92 L 01

Ch. Reigber, Ch. Foerste*, P. Schwintzer, F.-H. Massmann, H. Mueller,
Deutsches Geodaetisches Forschungsinstitut, Abt. I, Muenchen

*GeoForschungsZentrum, Potsdam

The solution (DGFII) 92 L 01 is an earth orientation, station position and station velocity solution derived by DGFI from all laser tracking data acquired in the period January 1980 to September 1991 from LAGEOS by fixed and mobile SLR systems of the international SLR network. The difference to the previous DGFI earth orientation and station position solution (DGFII) 91 L 01 is the extension of the LAGEOS analysis interval from 10.3 to 11.75 years.

The derived pole positions are referred to the position of the mean pole averaged over the period 1/1980 to 10/1986. This DGFI fixed origin of the pole departs from the CIO position by .045" in x and .286" in y.

The station coordinates are given for the reference epoch 1988.0.

## 1) COMPUTATION MODEL:

The models and constants underlying the (DGFII)92L01 solution and used for parameter estimation within the DGFI Orbit and Geodetic Parameter Estimation System (DOGS) are given in the following:

### Reference Frame

| | |
|---|---|
| CIS : | mean equator and equinox of J2000.0 |
| Precession : | IAU 1976 |
| Nutation : | IAU 1980 + DGFI correction(*) (Zhu and Reigber 1991) |
| Planetary Ephemerides : | JPL DE200/LE200 ephemerides |
| Initial Earth Rotation : | BIH87C02S homog. series, IERS Bulletin B (pole position transf. to zero mean pole: 1/1980 - 10/1986)(*) |
| Initial Station Coordinates : | GRIM4-S1 (Schwintzer *et al.* 1991) |
| Initial Station Velocities : | zero |
| Orientation of CTS : | stations 7086, 7090, 7105, 7109, 7122, 7210, 7834, 7835, 7840, 7907 (c.f. Bender and Goad 1979) |
| Time Evolution of Orientation : | common rotation with respect to AM0-2 plate motion model fixed to zero (same stations as above) |

### Dynamical Model

| | |
|---|---|
| GM : | 3.98600440 E+14 m**3 s**-2, C(0,0) solved |
| Semi Major Axis of Earth : | 6378136 m |
| Flattening 1/f : | 298.257810 |
| Angular Velocity of Earth : | 0.7292115 E-4 rad/s |
| Gravity Model of Earth : | GRIM4-S1 (truncated at l,m=25) (*) (Schwintzer *et al.* 1991) |
| C(2,1), S(2,1) : | applied, computed with respect to zero mean pole |

| | |
|---|---|
| Gravity Model of Moon : | Ferrari 77 (4*4) |
| Third Body : | Sun, Moon, Jupiter, Venus, Saturn, Mars, Mercury |
| Along Track Acceleration : | empirical (adjusted) |
| Albedo and Infrared : | Stephens model |
| Ocean Tides : | Schwiderski + GRIM4-S1(*) |
| Solid Earth Tides : | Wahr (2,2) model, k2=0.3, d=0, with permanent tide not removed |
| Relativistic Motion Equation : | harmonic isotropic |

**Measurement Model**

| | |
|---|---|
| Marini-Murray Refraction Model : | IERS standards |
| Solid Earth Tides Displacement : | IERS standards (Wahr model) |
| Ocean Loading Site Displacement : | based on Schwiderski model |
| Pole Tide : | IERS 1989 |
| Normal point elimin. criterion : | eliminated when created by 3 or less single ranges |

* - departures of IERS Standards

2) DATA

Two minute normal points are used for the solution (DGFII)92L01: 470,000 normal points generated by DGFII for the period January 1980 to April 1990, and 93,000 normal points generated by the Bendix Field Engineering Cooporation for the period May 1990 to Sept. 1991.

3) ANALYSIS PROCESS

The analysis was performed with the DGFI Orbit and Geodetic Parameter Estimation System (DOGS). DOGS consists of several macro modules. Those being used for the described analysis are the orbit computation module (DOGS-OC) and the reduction, accumulation and solution module (DOGS-CS). The processing sequence is as follows:

```
                 --------------------
                 ! Archived NP-Data !
                 --------------------
                         !------<-----------+
                    ===========    ------------------
                    ! DOGS-OC !    ! fine screening !   Orbit
                    ===========    ------------------   computation
                         !------>-----------+
             ----------------------------
             ! monthly normal equations !
             ----------------------------
                         !                              Reduction,
                    ===========                         accumulation,
                    ! DOGS-CS !                         solution
                    ===========                         of normal
                         !                              equations
     -----------------------------------------------
     !              multi-year solution            !
     -----------------------------------------------
```

DOGS-OC is used for orbit computation, fine screening of data, and for the creation of monthly arc normal equations. DOGS-CS is firstly providing the reduced normal equations, secondly accumulating several reduced normal equations including datum constraints and eccentricity conditions, and thirdly solving the 11.75 years combined normal equation system simultaneously for all parameters listed below.

4) GEODETIC DATUM

The solution is minimum constrained. Since the origin of the reference system is the geocentre by setting the first degree and order terms of the gravity model to zero and the scale being defined by the velocity of light, the orientation remains to be defined. This is done by forcing the common rotation between the initial and the adjusted coordinates of a selected set of stations to become zero (Bender and Goad 1979).

In the same way the drift in orientation about the three coordinate axes is forced to be the same as derived from a given set of horizontal station velocities inferred by a geophysical plate motion model, presently being the AM0-2 model (Minster and Jordan 1978).

5) ECCENTRICITY CONDITIONS

In order to achieve reasonable drift rates on stations successively occupied by different systems some conditions have to be applied: coordinate rates referring to the same site are set equal and eccentricity values (survey ties) between two occupations are introduced as external observations if available and proved to be correct. In contrary, some occupations had to be divided into separate occupations, because a discontinuity appeared somewhere in the data.

6) ADJUSTED PARAMETERS

The adjusted parameters are listed in the following table:

| | |
|---|---|
| Gravity Field Parameters | : C(0,0) |
| Direct Solar Radiation Pressure | : CR (per 15 days) |
| Along Track Acceleration | : CA (per 15 days) |
| Orbital State Vector | : 6 parameters per 30 days |
| Polar Motion | : one x and y parameter per 5 days |
| LOD | : one parameter per 5 days |
| Station Coordinates | : geocentric coordinates X, Y, Z |
| Velocity of Stations | : north and east direction (phidot, lambdadot*cos(phi)) |

Some of these parameters have been reduced in the monthly normal equations before combining the equations to a multi-year system in order to reduce the size of the system. The solution has 198 sets of X-, Y- ,Z- station coordinate parameters. Only horizontal station velocities were solved for. For stations with a time span of the observations shorter than one year no station velocities were solved for. There are North and East velocity parameters solved for 46 observation sites.

7) RESULTS

The results consist of Earth orientation parameters for the 11.75 years interval, station coordinates and velocities. They are available on request from the Central Bureau of IERS.

**References**

Bender, P., Goad, C., 1979: Probable LAGEOS Contributions to a Worldwide Geodynamics Control Network. *The Use of Artificial Satellites for Geodesy and Geodynamics*, Eds. G. Veis and E. Livieratos, Athens (Greece), Publication of the National Technical University, Vol. II, pp 145-161.

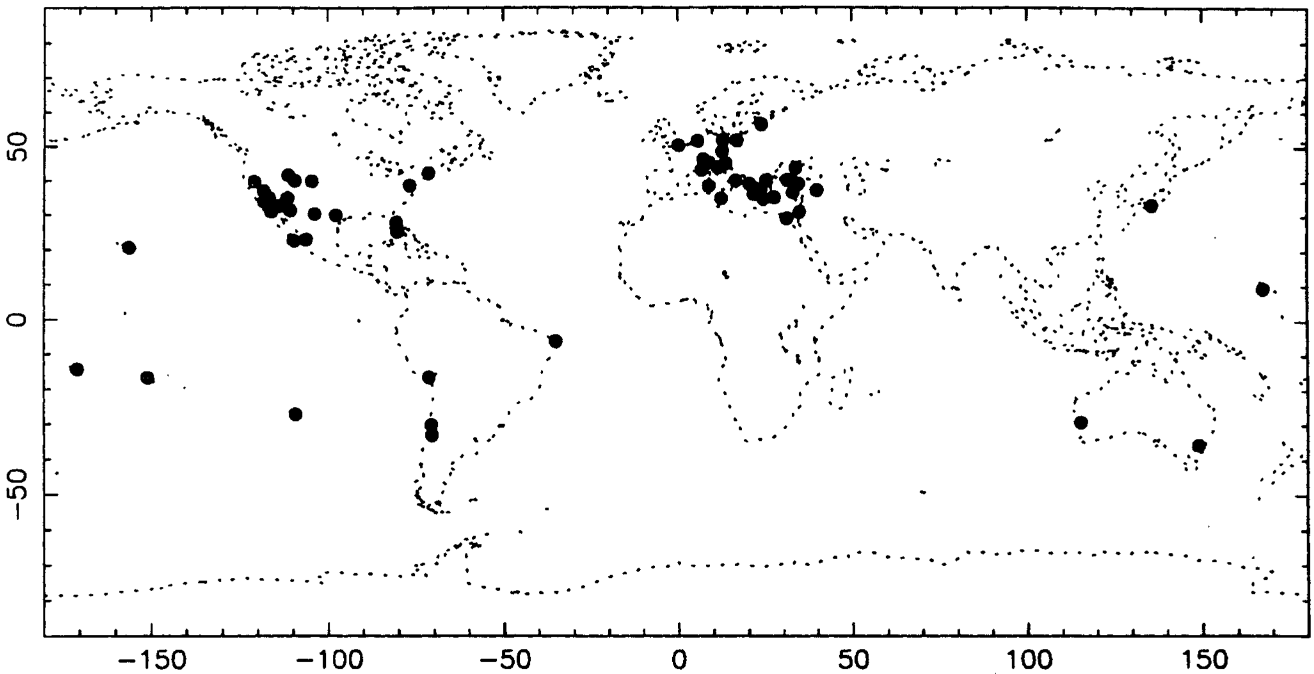
Minster, J.B., Jordan, T.H., 1978: Present-Day Plate Motions, *J. Geophys. Res.*, **83**, B11, pp 5331-5354.

Schwintzer, P., Reigber, Ch., Massmann, F.H., Barth, W., Raimondo, J.C., Gerstl, M., Li, H., Biancale, R., Balmino, G., Moynot, B., Lemoine, J.M., Boudon, J., Barlier, F. 1991: A New Earth Gravity Field Model in Support of ERS-1 and SPOT2: GRIM4-S1/C1, *Technical Report to the German Space Agency (DARA) and the French Space Agency (CNES)*, DGFI/GRGS, Muenchen/Toulouse.

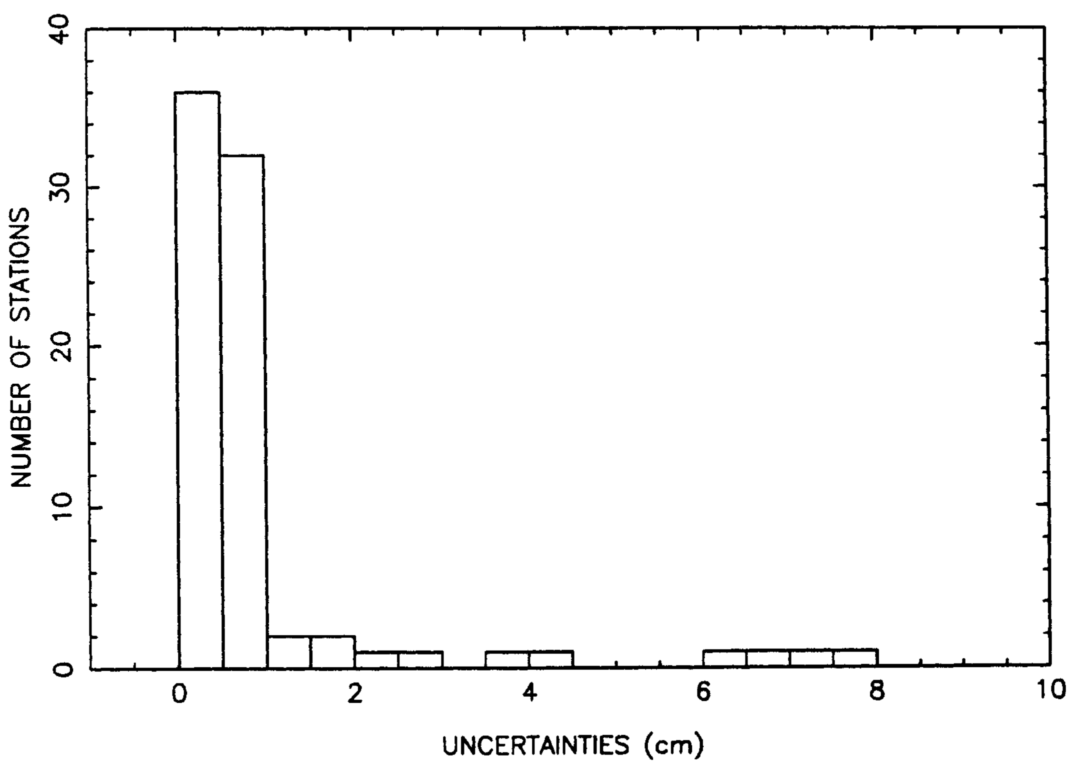
Zhu, S.Y., Reigber, Ch., 1991: The German PAF for ERS-1: ERS-1 Standards used at D-PAF, *D-PAF Document ERS-D-STD-31101*, Muenchen.

**Summary description of the terrestrial system attached to the set of station coordinates SSC(DGFII) 92 L 01**

| | |
|---|---|
| 1 - Technique : | SLR |
| 2 - Analysis Center : | DGFI, Dept.I, Munich |
| 3 - Solution identifier : | SSC(DGFII) 92 L 01 |
| 4 - Software used : | D O G S (DGFI Orbit and Geod. Parameter Estimation System) |
| 5 - Relativity scale : | LE |
| 6 - Permanent tidal correction on station : | not included |
| 7 - Tectonic plate model : | no a priori model |
| 8 - Velocity of light : | 299792458 m/sec |
| 9 - Gravit. const. * Earth mass (GM) : | 3.986004396E+14 m*3/s**2 (adjusted) |
| 10 - Reference epoch : | 1988.0 ( MJD 47161.0 ) |
| 11 - Adjusted parameters : | C00, X,Y,Z, Lamdadot*cos(phi),phidot (for 11.75 years)<br>LAGEOS state vector at epoch (at monthly intervals)<br>CR, CA (at 15 day intervals)<br>PX, PY, LODR (at 5 day intervals) |
| 12 - Definition of origin : | geocentre |
| 13 - Definition of the orientation : | common rotation angle between initial and adjusted coordinates of 10 stations forced to be zero |
| 14 - Constraint for time evolution : | drift in orientation around the three coordinate axes is forced to be the same as derived from a given set of AM0-2 horizontal station position velocities. |




Distribution of the 60 sites of the terrestrial frame SSC(DGFII) 92 L 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 81 stations of the terrestrial frame SSC(DGFII) 92 L 01. 1 station with uncertainty larger than 10 cm is not shown.

EOP(DGFII) 92 L 01 From Jan 1980 to Sep 1991

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

| YEAR | X | | Y | | D | |
|---|---|---|---|---|---|---|
| | Nb | Sigma | Nb | Sigma | Nb | Sigma |
| 1980 | 73 | 0.70 | 73 | 0.40 | 73 | 0.07 |
| 1981 | 73 | 0.70 | 73 | 0.40 | 73 | 0.07 |
| 1982 | 73 | 0.50 | 73 | 0.40 | 73 | 0.06 |
| 1983 | 73 | 0.50 | 73 | 0.40 | 73 | 0.05 |
| 1984 | 73 | 0.30 | 73 | 0.30 | 73 | 0.04 |
| 1985 | 73 | 0.30 | 73 | 0.20 | 73 | 0.03 |
| 1986 | 73 | 0.30 | 73 | 0.30 | 73 | 0.03 |
| 1987 | 73 | 0.30 | 73 | 0.30 | 73 | 0.03 |
| 1988 | 73 | 0.30 | 73 | 0.30 | 73 | 0.03 |
| 1989 | 73 | 0.30 | 73 | 0.30 | 73 | 0.04 |
| 1990 | 73 | 0.30 | 73 | 0.30 | 73 | 0.03 |
| 1991 | 55 | 0.30 | 55 | 0.30 | 55 | 0.04 |

# EARTH ROTATION AND STATION COORDINATES COMPUTED FROM SLR OBSERVATIONS ON LAGEOS

DUT 92 L 01

R. Noomen, B.A.C. Ambrosius, H. Leenman, G.J. Mets, K.F. Wakker
Delft University of Technology, Faculty of Aerospace Engineering,Kluyverweg 1, 2629 HS Delft, The Netherlands

The solution ERP/SSC(DUT) 92 L 01 consists of a coherent set of Earth Rotation Parameters (ERPs), determined at 5-day intervals, and coordinates of a global laser station network. The solution was computed from laser range observations on the geodetic satellite LAGEOS, taken during the period January 1986 through December 1990.

For the analysis, the 5-year data interval was divided into a total of 21 sub-periods, with a length of 13 weeks on average. The actual analysis was performed in a 2-step approach.

First, a continuous but mutually independent series of 21 global network and ERP solutions was computed by analyzing each batch of observations. The parameter estimation was based on a least-squares fit of the satellite orbit to the SLR 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-period was further divided into a series of 7-day data arcs and satellite parameters (state-vector at epoch, solar reflectivity and along-track acceleration parameter) were estimated for each individual data arc.

To prevent computational singularities, the parameters were constrained in a Bayesian way.

The a priori standard deviation of the pole position and UT1 were assigned values of 0.1 arcsec and 0.01 s, respectively, with a priori values taken from the monthly IERS Bulletins B. 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 data screening.

The computation model is summarized in Table 1. The model closely follows the IERS Standards, with few exceptions: (i) the GEM-T2 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 on station coordinates was not applied; and (iii) no plate motion was applied during each "13-week" sub-period. Details of the terrestrial system are given in Table 2.

The second step was primarily aimed at bringing coherency into the series of parameter solutions. This was done by fitting a model for tectonic deformations to the series of individual station coordinates, while eliminating systematic differences. This model consists of initial station coordinates at a reference epoch and the time-derivatives of these coordinates. A priori values for these time-derivatives were taken from the NUVEL-1 No Net Rotation model, and either kept fixed for a sub-set of 12 SLR stations, which are known to follow the motions described by this model, or estimated for the remainder of the stations.

Next, the resulting model for instantaneous station positions was back-substituted into the GEODYN/SOLVE data reduction programs. Finally, new solutions for the ERPs were computed without application of any constraint, and keeping the station positions (and the ascending nodes) fixed. The computation model is identical to the one for step 1, already listed in Table 1.

The resulting series of ERP solutions and the station coordinates solution are available on request from the Central Bureau of IERS. 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. In UT1, the effect of short-term perturbations, caused by zonal tides, has been removed.

Table 1: Models and constants.

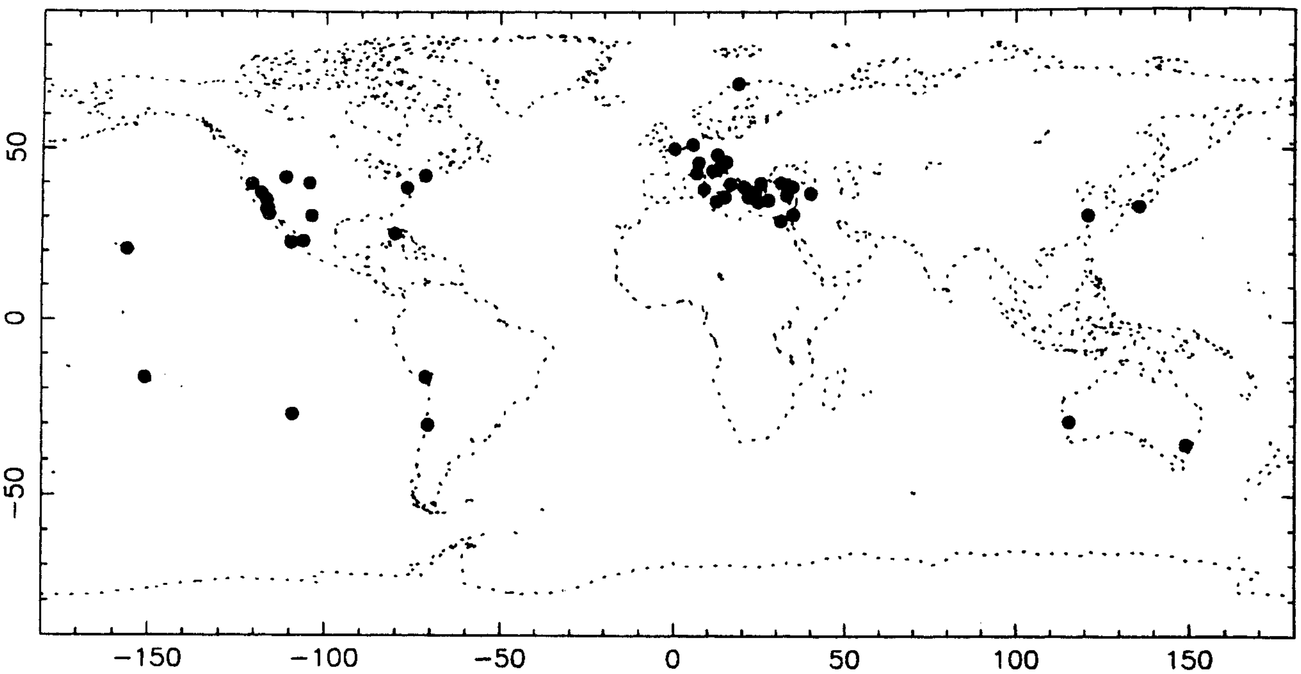
| | |
|---|---|
| DYNAMIC MODEL: | |
| Gravity field : | NASA/GSFC GEM-T2 model, truncated at 20x20; C(2,1) and S(2,1) according to IERS Standards (1989) |
| GM : | 398600.4360 km**3/s**2 |
| c : | 299792.458 km/s |
| ae : | 6378.1370 km |
| 1/f : | 298.257 |
| Solar and lunar attraction : | JPL DE200 ephemeris |
| Solid earth tides : | Wahr model |
| Ocean tides : | NASA/GSFC GEM-T2 model |
| Solar radiation : | CR adjusted; occultation by Earth and Moon; umbra and penumbra |
| Along-track acceleration : | AT 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); modelled with NUVEL-1 NNR (step 2) |
| Earth rotation : | adjusted at 5-day intervals; a priori values from IERS Bulletin B |
| CIS : | mean equator and equinox of J2000.0 |
| Precession : | IAU 1976 (Lieske model) |
| Nutation : | IAU 1980 (Wahr model) plus Herring correction |
| Plate motion : | not applied |
| Tidal uplift : | h2 = 0.609, l2 = 0.0852 |
| Pole tide (geometric part) : | applied |
| Ocean loading : | not applied |
| MEASUREMENT MODEL: | |
| Observations : | Release B normal points, computed at DGFI (January - October 1986, 1987), DUT (November, December 1986) and Bendix (1988 - 1990) |
| Data weighting : | determined from overall model accuracy and system characteristics |
| Tropospheric refraction: | Marini-Murray model |

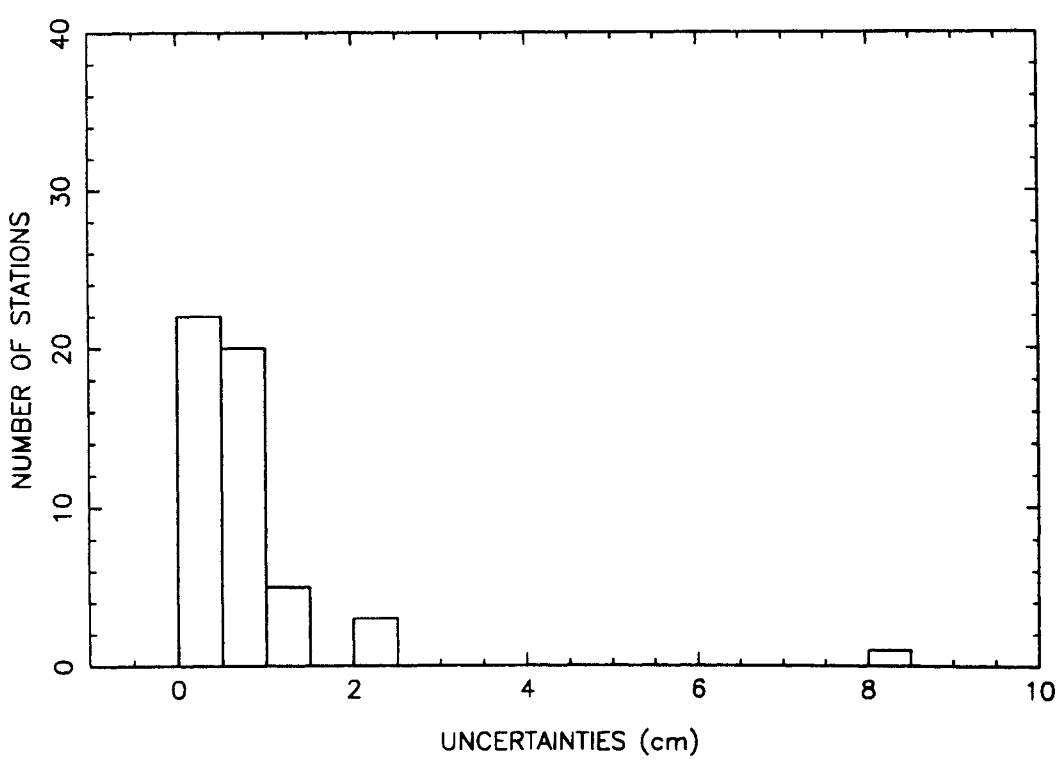
Table 2.

**Summary description of the terrestrial system attached to the set of station coordinates SSC (DUT) 92 L 01**

| | |
|---|---|
| 1- Technique : | SLR |
| 2- Analysis center : | DUT |
| 3- Solution identifier : | SSC(DUT) 92 L 01 |
| 4- Software used : | GEODYN-2/SOLVE-2 |
| 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 : | 398600.4360 km**3/s**2 |
| 10- Reference epoch : | January 1, 1988 |
| 11- Adjusted parameters : | X0, Y0, Z0 (for selected stations);<br>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 48 sites of the terrestrial frame SSC(DUT) 92 L 01




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 52 stations of the terrestrial frame SSC(DUT) 92 L 01. 1 station with uncertainty larger than 10 cm is not shown.

EOP(DUT) 92 L 01 From Jan 1986 to Dec 1990

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 |
| 1986 | 72 | 0.23 | 72 | 0.19 | 72 | 0.17 |
| 1987 | 72 | 0.19 | 72 | 0.17 | 72 | 0.15 |
| 1988 | 73 | 0.18 | 73 | 0.18 | 73 | 0.14 |
| 1989 | 73 | 0.18 | 73 | 0.17 | 73 | 0.15 |
| 1990 | 73 | 0.16 | 73 | 0.16 | 73 | 0.14 |

# EARTH ROTATION AND STATION COORDINATES FROM 1983 - 1991 LAGEOS OBSERVATIONS ANALYSIS GAOUA 92 L 01

A.I. Emets, V.N. Salyamov, V.K. Tarady

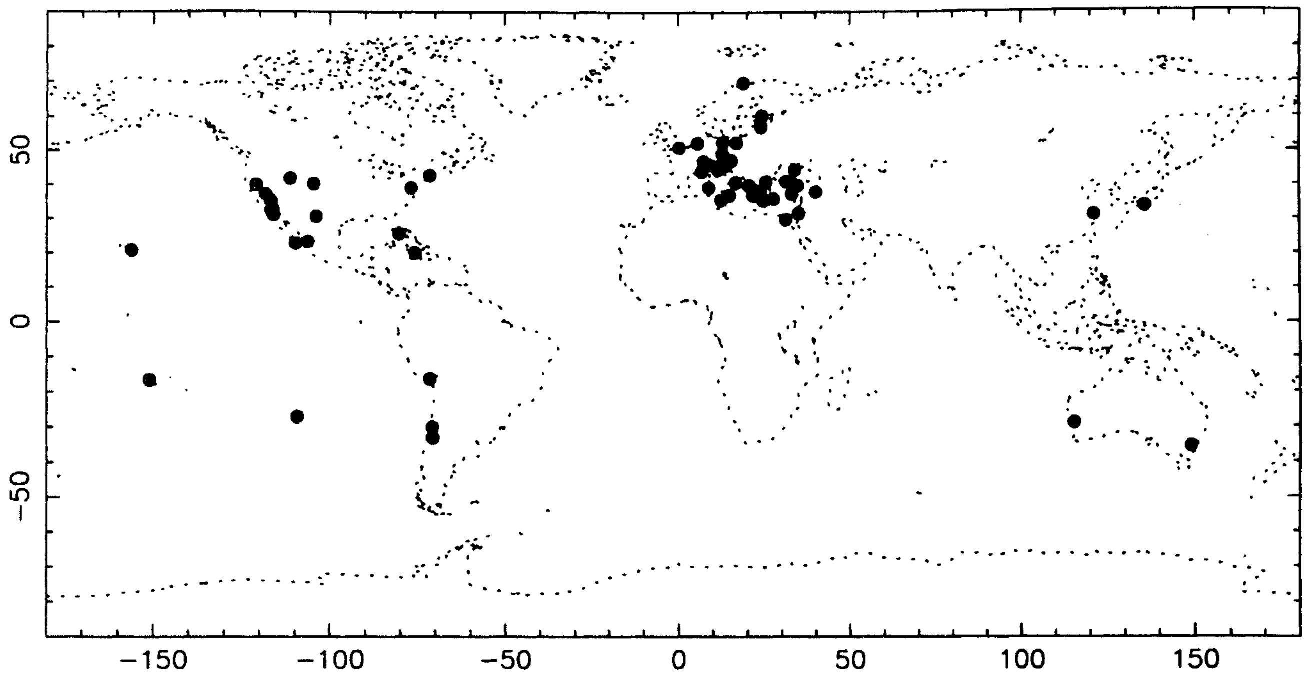
A set of 72 station cartesian coordinates and a EOP series have been determined from 468415 Lageos normal points involving the period of 8 years from september 1983 through sepember 1991. Kiev-Geodynamics-4 software based on numerical Adams method with a variable step and integration order and on the most of IERS recommendation has been used for data analysis. The differences from IERS Standards are the same as described in previous solution GAOUA 91 L 01.

Data processing consists of two stages. First 15-day arcs were used to determine 6 orbit elements. Second station coordinates as global parameters, were estimated simultaneously with orbit elements ( excluding ascending node longitude ), EOP and their rates of change on 5-day subarcs, the coefficients of reflectivity and along-track acceleration on 15-day arcs as the local ones. Computer capabilities entail two passes through the data at this stage. The global parameters are known after the first pass, and other parameters after the second one.

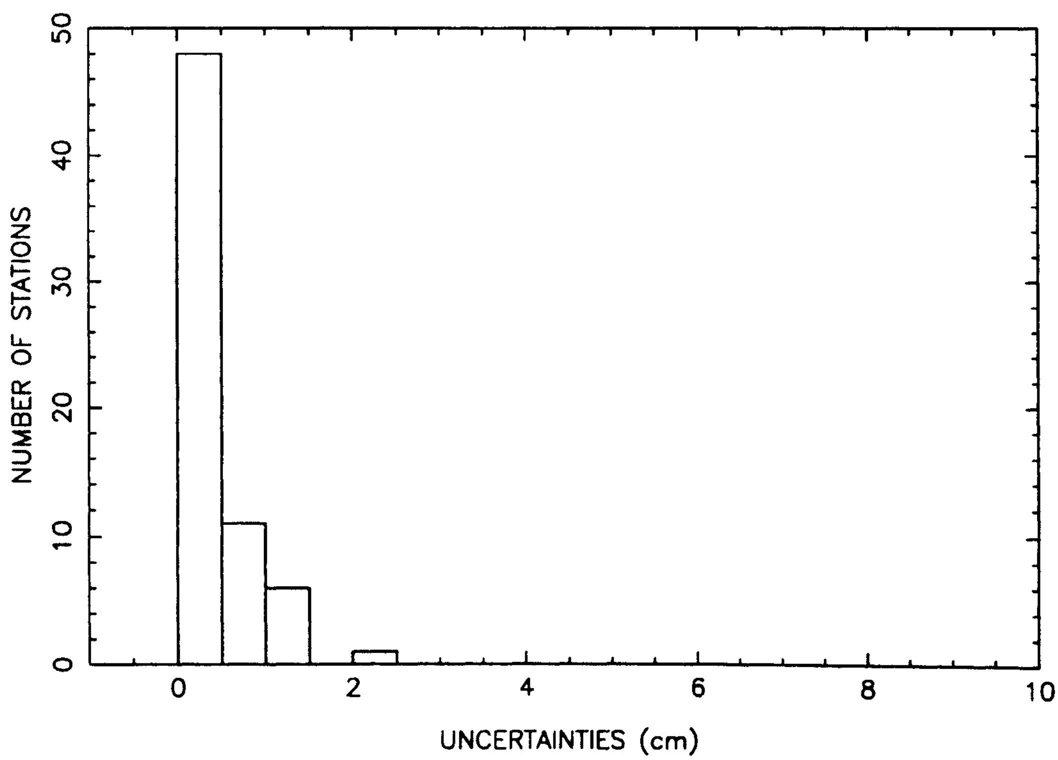
In order to provide the connection of SSC(GAOUA) 92 L 01 to ITRF88 reference system Grasse station (7835) longitude and Herstmontceux station (7840) longitude and latitude were held fixed. The station motions were constrained by Minster and Jordan AM0-2 model with reference epoch MJD 47161. A priori values for EOP were taken from BIH Annual Reports and IERS Bulletin B. UT1R values in each first subarc were held fixed.

**Summary description of the terrestrial system attached to the set of station coordinates SSC (GAOUA) 92 L 01**

| | |
|---|---|
| 1 - Technique : | SLR |
| 2 - Analysis Center : | GAOUA |
| 3 - Solution identifier : | SSC(GAOUA) 92 L 01 |
| 4 - Software used : | KIEV-GEODYNAMICS - 4 |
| 5 - Relativity scale : | LE |
| 6 - Permanent tidal correction on station : | NO |
| 7 - Tectonic plate model : | AM0-2 |
| 8 - Velocity of light : | 299 792 458 |
| 9 - Geogravitational constant (GM) : | 3.9860 0440*10**14 |
| 10 - Reference epoch : | MJD 47161 |
| 11 - Adjusted parameters : | X,Y,Z |
| 12 - Definition of the origin : | C10=0, C11=0, S11=0 |
| 13 - Definition of the orientation : | ERP values from IERS Bulletin B |
| 14 - Constraint for time evolution : | fixed plate motion model |




Distribution of the 57 sites of the terrestrial frame SSC(GAOUA) 92 L 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 67 stations of the terrestrial frame SSC(GAOUA) 92 L 01. 1 station with uncertainty larger than 10 cm is not shown.

EOP(GAOUA)92 L 01 From Sep 1983 to Oct 1991

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 | 24 | 0.40 | 24 | 0.30 | 16 | 0.30 |
| 1984 | 73 | 0.30 | 73 | 0.20 | 48 | 0.25 |
| 1985 | 73 | 0.20 | 73 | 0.10 | 49 | 0.20 |
| 1986 | 73 | 0.20 | 73 | 0.20 | 49 | 0.20 |
| 1987 | 73 | 0.20 | 73 | 0.10 | 48 | 0.20 |
| 1988 | 73 | 0.20 | 73 | 0.10 | 49 | 0.20 |
| 1989 | 73 | 0.20 | 73 | 0.20 | 49 | 0.20 |
| 1990 | 73 | 0.20 | 73 | 0.10 | 48 | 0.20 |
| 1991 | 56 | 0.30 | 56 | 0.20 | 38 | 0.20 |

# EARTH ORIENTATION AND STATION COORDINATES BY LAGEOS LASER RANGING DATA FROM 1980 TO SEPTEMBER 1991

GFZ 92 L 01
GFZ 92 L 02
GFZ 92 L 03
GFZ 92 L 04

H. Montag, G. Gendt, G. Dick, Th. Nischan, W. Sommerfeld
GeoForschungsZentrum (GFZ), Potsdam

## SOFTWARE AND DATA

Altogether two Sets of Station Coordinates (SSC(GFZ) L 01, L 02) and four sets of Earth Rotation Parameters (EOP(GFZ) L 01 ... L 04) were derived from Satellite Laser Ranging (SLR) data to LAGEOS using the improved POTSDAM-5 software package. These solutions were based on normal points of the IERS stations from the beginning of 1980 (MJD 44238) until September 1991 (MJD 48519), in total 38711 passes from 100 stations. A statistical summary (station fits for 5-day orbit adjustment together with number of passes and observations) for 1990 and 1991 is given in Table 1.

The constants and model parameters used for these solutions conform to the IERS Standards (draft 1992) with the following differences:

- tidal variations in UT1 caused by zonal tides with periods bigger than 35 days not considered
- LAGEOS center of mass correction 0.251 m
- nutation-corrections by VLBI for
  46799-47519 from ANNUAL REPORT 1988 p. II-68
  47529-48519 from IERS BULLETIN B.

In a multistage-multiarc procedure different parameters were solved for as given in the summary sheet. Here also details on the adopted model for the terrestrial system are listed.

## STATION COORDINATES AND VELOCITIES

For the main solution SSC(GFZ) 92 L 01 the coordinates of all sites were adjusted simultaneously with site velocities using data from the whole time interval. For 74 stations the data distribution was good enough to determine site velocities, whereas the velocities of the other stations were held fixed to that of the NUVEL-1 model. In a second variant (additional solution SSC(GFZ) 92 L 02) all site velocities were fixed to that predicted by NUVEL-1 rigid plate model (de Mets *et al.*, 1990). In the adjustment some constraints were incorporated :

- marker eccentricity parameters according to NASA CDP
- colocated markers must have the same velocity
- colocated markers should have the given differences (*IERS Technical Note* 5 ,1989 and *NASA CDP, Catalogue of Site Informations,* 1989):
  7035 to 7062; 7080 to 7885; 7105 to 7063, 7103, 7125, 7899, 7918 and 7920; 7109 to 7886; 7288 to 7265; 7834 to 7596; 7853 to 7114, 7939 to 7540 and 7541.

For the stations Wettzell (7834) and Grasse (7835) significantly different positions were adjusted in 1980 to 1982, not understood up to now; thus fictive occupations were assigned to these stations (783599 from 1980 to 1982, 783497 in 1980, 783498 in 1981, 783499 in 1982).

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 longtitude of the station 7840 and the latitude of the station 7105. Additionally, no common net rotation was permitted in relation to the reference coordinate set ITRF89. Corrections due to the permanent tidal deformation of the Earth were applied.

The station coordinates and the adjusted velocities for the 74 sites mentioned above are available on request from the Central Bureau of IERS. The given errors have been scaled with a factor 5, because the calculated errors seem to be too optimistic.

EARTH ROTATION PARAMETERS

For the EOP (pole coordinates and length of day - LOD) two sets with 5-day time resolution were computed. The main solution EOP(GFZ) 92 L 01 refers to the SSC(GFZ) 92 L 01 with adjusted site velocities and the EOP(GFZ) 92 L 04 is based on SSC(GFZ) 92 L 02 with motion fixed to NUVEL-1. Starting from the MERIT-Campaign (September 1983) thanks to the better data distribution two additional sets (EOP(GFZ) 92 L 02, L 03) with a higher resolution of 3 and 2 days, respectively, were determined. For these series the station coordinates SSC(GFZ) 92 L 01 were introduced.

The results show a good agreement with the previously reported series of ZIPE (for time intervals 1984 -1989) and with IERS results. The differences between EOP results obtained on the basis of adjusted site velocities and those derived by fixed to NUVEL-1 site velocities are not significant.

Whereas in the 5-day solutions the LOD values were estimated directly, in the L02 and L03 solutions UT1 values were solved for instead of LOD. These UT1 results were converted into LOD. That means that the time scales (col.1) for the EOP(GFZ) 92 L 02 and L 03 have to be transferred for the LOD values by -1.5 d and -1.0 d, respectively.

Generally, the SLR data were weighted according to their estimated accuracy. In addition, several non-permanent stations were provided with smaller weights in order to reduce the influence of the change of the station distribution. No post-adjustment smoothing or filtering procedure was applied to the EOP series.

The standard deviations of the EOP series are about ±0.1 to ±0.2 mas for the pole coordinates and ±0.001 to ±0.003 ms for LOD if there are enough relevant data submitted. Mainly because of this data effect the precision was significantly increased in the course of the last ten years. The accuracy was estimated to be about ±1 mas and ±0.1 ms, respectively. In cases of poor data distribution the errors can be several times lager. Therefore, several single results showing large deviations caused by a too small number of data (only about two to four relevant passes) were omitted.

**References**

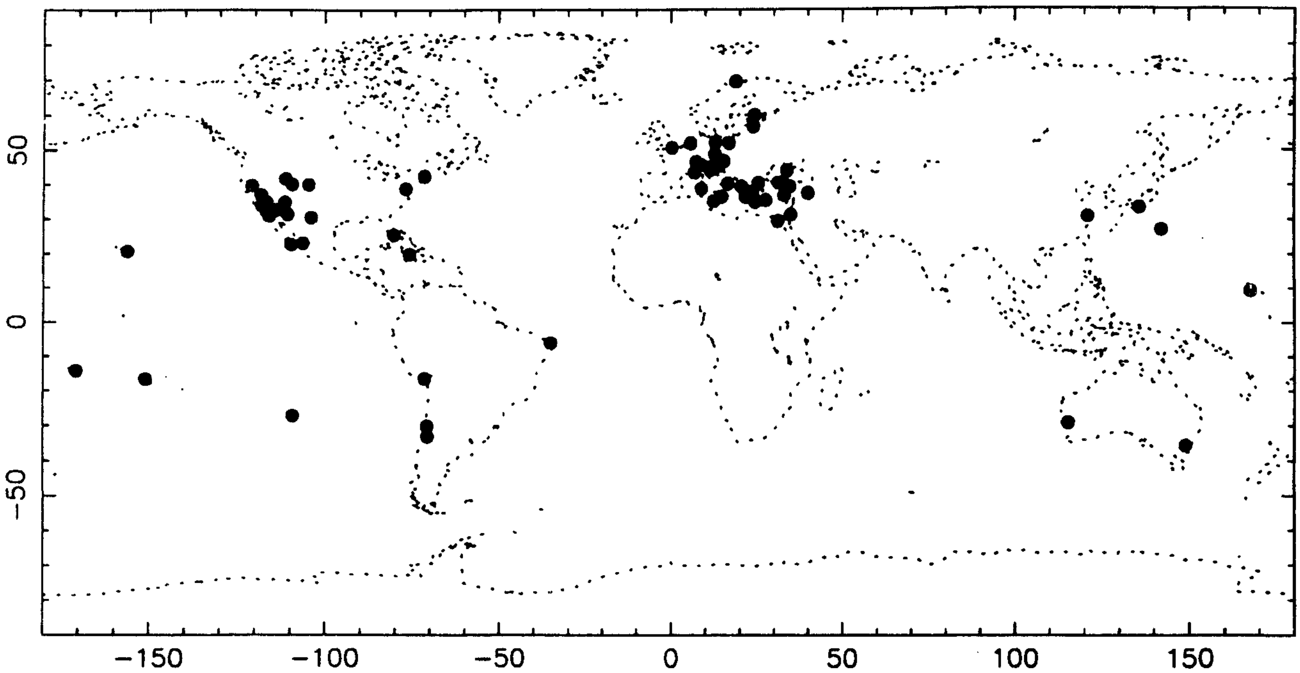
DeMets, C., Cordan, R.G., Argus, D.F., and Stein S., 1990: Current plate motions, *Geophys. J. Int.*, **101**, 425-478.

Table 1. Summary of statistical information for 1990-1991

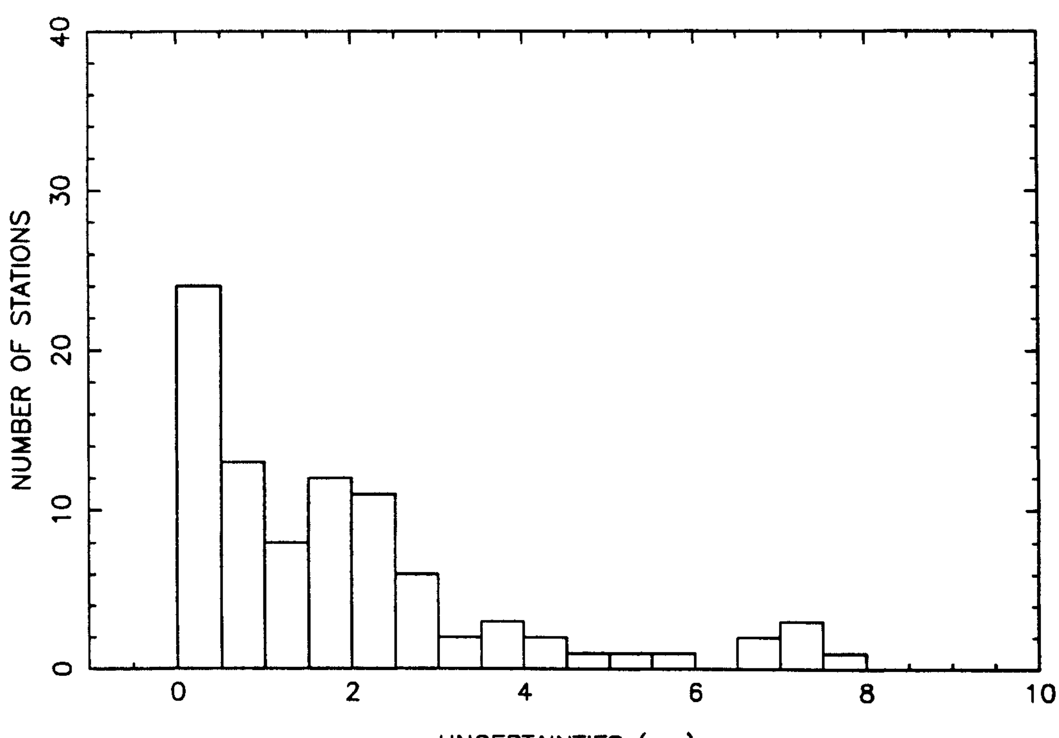
| station | Number of passes | Number of obs. | mean rms (m) | station | Number of passes | Number of obs. | mean rms (m) |
|---|---|---|---|---|---|---|---|
| 118101 | 136 | 1071 | 0.164 | 7542 | 6 | 50 | 0.030 |
| 187301 | 85 | 639 | 0.130 | 7543 | 47 | 530 | 0.036 |
| 188401 | 90 | 889 | 0.160 | 7545 | 36 | 436 | 0.044 |
| 189301 | 20 | 177 | 0.106 | 7602 | 45 | 444 | 0.027 |
| 195301 | 33 | 148 | 0.189 | 7805 | 6 | 29 | 0.428 |
| 7046 | 62 | 920 | 0.031 | 7810 | 315 | 3954 | 0.040 |
| 7080 | 309 | 3079 | 0.043 | 781102 | 72 | 627 | 0.121 |
| 7090 | 409 | 6891 | 0.025 | 7831 | 120 | 1063 | 0.046 |
| 7091 | 50 | 747 | 0.032 | 7834 | 191 | 1920 | 0.038 |
| 7097 | 82 | 914 | 0.042 | 7835 | 892 | 14182 | 0.036 |
| 7105 | 195 | 2815 | 0.026 | 7837 | 136 | 1468 | 0.089 |
| 7109 | 303 | 4105 | 0.021 | 7838 | 111 | 1415 | 0.045 |
| 7110 | 607 | 9427 | 0.025 | 7839 | 238 | 3132 | 0.031 |
| 7112 | 51 | 688 | 0.039 | 7840 | 677 | 7295 | 0.034 |
| 7122 | 203 | 2877 | 0.030 | 7843 | 290 | 3628 | 0.029 |
| 7123 | 76 | 936 | 0.035 | 7853 | 40 | 529 | 0.054 |
| 7210 | 53 | 4668 | 0.029 | 7907 | 163 | 2274 | 0.082 |
| 7288 | 47 | 720 | 0.028 | 7918 | 77 | 986 | 0.028 |
| 7295 | 51 | 681 | 0.028 | 7920 | 13 | 143 | 0.090 |
| 7401 | 143 | 2158 | 0.042 | 7939 | 461 | 6656 | 0.064 |
| 7403 | 186 | 2644 | 0.031 | 8833 | 30 | 289 | 0.031 |
| 7515 | 42 | 519 | 0.040 | 883401 | 124 | 1236 | 0.058 |
| 7525 | 28 | 361 | 0.039 | | | | |

**Summary description of the terrestrial systems attached to the sets of station coordinates SSC(GFZ) 92 L 01 and 92 L 02.**

1 - Technique : SLR
2 - Analysis Center : GFZ
3 - Solution Identifier : SSC(GFZ) 92 L 01 and SSC(GFZ) 92 L 02
4 - Software Used : POTSDAM-5
5 - Relativity Scale : Geocentric (LE)
6 - Permanent Tidal Correction on station : Yes
7 - Tectonic Plate model : adjusted (L01) resp. NUVEL-1 (L02)
8 - Velocity of light : 299792458 m/sec
9 - Geogravitational constant (GM): adjusted to 398600.4420 km3/s2
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 (L02: velocities are fixed to NUVEL-1)
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 2- and 3-day intervals (were 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 : L 01 - constraints on net rotation by fixing the velocities of:
- the latitude of 7105, 7840
- the longtitude of 7840




Distribution of the 66 sites of the terrestrial frame SSC(GFZ) 92 L 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 94 stations of the terrestrial frame SSC(GFZ) 92 L 01. 4 stations with uncertainties larger than 10 cm are not shown.

EOP(GFZ) 92 L 01 From Jan 1980 to Sep 1991

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

| YEAR | X | | Y | | D | |
|---|---|---|---|---|---|---|
| | Nb | Sigma | Nb | Sigma | Nb | Sigma |
| 1980 | 66 | 0.46 | 66 | 0.25 | 66 | 0.04 |
| 1981 | 65 | 0.40 | 65 | 0.22 | 65 | 0.03 |
| 1982 | 70 | 0.34 | 70 | 0.19 | 70 | 0.03 |
| 1983 | 70 | 0.23 | 70 | 0.20 | 70 | 0.02 |
| 1984 | 73 | 0.14 | 73 | 0.11 | 73 | 0.01 |
| 1985 | 73 | 0.10 | 73 | 0.08 | 73 | 0.01 |
| 1986 | 73 | 0.11 | 73 | 0.09 | 73 | 0.01 |
| 1987 | 73 | 0.10 | 73 | 0.08 | 73 | 0.01 |
| 1988 | 73 | 0.10 | 73 | 0.09 | 73 | 0.01 |
| 1989 | 73 | 0.10 | 73 | 0.09 | 73 | 0.01 |
| 1990 | 73 | 0.08 | 73 | 0.09 | 73 | 0.01 |
| 1991 | 52 | 0.10 | 52 | 0.09 | 52 | 0.01 |

EOP(GFZ) 92 L 02 From Jul 1983 to Sep 1991

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

| YEAR | X | | Y | | D | |
|---|---|---|---|---|---|---|
| | Nb | Sigma | Nb | Sigma | Nb | Sigma |
| 1983 | 56 | 0.24 | 56 | 0.22 | 56 | 0.17 |
| 1984 | 121 | 0.19 | 121 | 0.16 | 122 | 0.14 |
| 1985 | 122 | 0.14 | 122 | 0.11 | 121 | 0.10 |
| 1986 | 121 | 0.14 | 121 | 0.12 | 122 | 0.11 |
| 1987 | 122 | 0.13 | 122 | 0.12 | 121 | 0.11 |
| 1988 | 121 | 0.13 | 121 | 0.12 | 122 | 0.10 |
| 1989 | 122 | 0.14 | 122 | 0.13 | 121 | 0.11 |
| 1990 | 120 | 0.11 | 120 | 0.12 | 121 | 0.10 |
| 1991 | 88 | 0.13 | 88 | 0.13 | 87 | 0.10 |

EOP(GFZ) 92 L 03 From Jul 1983 to Sep 1991

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

| YEAR | X | | Y | | D | |
|---|---|---|---|---|---|---|
| | Nb | Sigma | Nb | Sigma | Nb | Sigma |
| 1983 | 78 | 0.30 | 78 | 0.26 | 78 | 0.21 |
| 1984 | 178 | 0.23 | 178 | 0.19 | 178 | 0.17 |
| 1985 | 176 | 0.17 | 176 | 0.14 | 177 | 0.13 |
| 1986 | 177 | 0.17 | 177 | 0.14 | 176 | 0.13 |
| 1987 | 180 | 0.16 | 180 | 0.15 | 180 | 0.14 |
| 1988 | 175 | 0.16 | 175 | 0.14 | 175 | 0.13 |
| 1989 | 177 | 0.17 | 177 | 0.16 | 177 | 0.14 |
| 1990 | 180 | 0.13 | 180 | 0.15 | 181 | 0.12 |
| 1991 | 128 | 0.15 | 128 | 0.15 | 127 | 0.12 |

EOP(GFZ) 92 L 04 From Jan 1980 to Sep 1991

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

| YEAR | X | | Y | | D | |
|---|---|---|---|---|---|---|
| | Nb | Sigma | Nb | Sigma | Nb | Sigma |
| 1980 | 66 | 0.47 | 66 | 0.25 | 66 | 0.04 |
| 1981 | 65 | 0.41 | 65 | 0.23 | 65 | 0.03 |
| 1982 | 70 | 0.36 | 70 | 0.21 | 70 | 0.03 |
| 1983 | 70 | 0.26 | 70 | 0.21 | 70 | 0.02 |
| 1984 | 73 | 0.14 | 73 | 0.11 | 73 | 0.01 |
| 1985 | 73 | 0.11 | 73 | 0.09 | 73 | 0.01 |
| 1986 | 73 | 0.11 | 73 | 0.09 | 73 | 0.01 |
| 1987 | 73 | 0.10 | 73 | 0.08 | 73 | 0.01 |
| 1988 | 73 | 0.10 | 73 | 0.09 | 73 | 0.01 |
| 1989 | 73 | 0.11 | 73 | 0.10 | 73 | 0.01 |
| 1990 | 73 | 0.09 | 73 | 0.10 | 73 | 0.01 |
| 1991 | 52 | 0.11 | 52 | 0.10 | 52 | 0.01 |

EARTH ORIENTATION PARAMETERS FROM GSFC SOLUTION SL8.1 GSFC 92 L 01

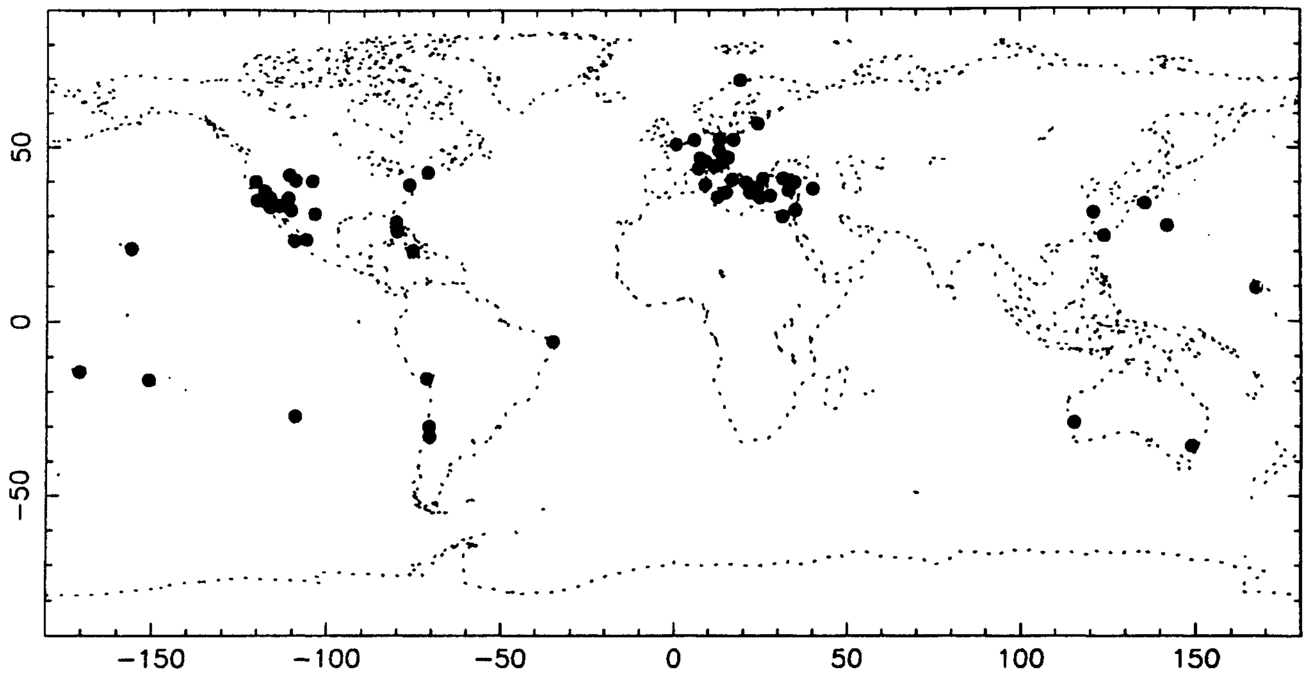
D.E. Smith and R. Kolenkiewicz
NASA/Goddard Space Flight Center, Greenbelt MD 20771
P.J. Dunn, S.M. Klosko, J.W. Robbins, M.H. Torrence and R.G. Williamson
Hughes/ S T Systems Corp.,Lanham MD 20706
E.C. Pavlis
U. of Md. Dept. of Astronomy and NASA/GSFC, Greenbelt MD 20771

The SL8 solution was obtained by fitting the orbit of LAGEOS in 30 day (and occasionally 35 day) arcs using normal points generated from full rate data collected between January 1980 and December 1991. The monthly arcs were combined to form a solution for a set of station positions at epoch 860701, moving according to the SL7 station velocity model when there were significant differences from NUVEL-1. Orbit and force model parameters were adjusted at the intervals listed below. Earth Orientation Parameters were estimated as independent values of time and polar motion at daily intervals since January 1983, and at 5 day intervals up to December 1982. The IERS standards were followed with the exception that the GEM-T3 gravity field with expanded ocean tidal terms was adopted and the value of the geogravitational constant was employed as listed below.

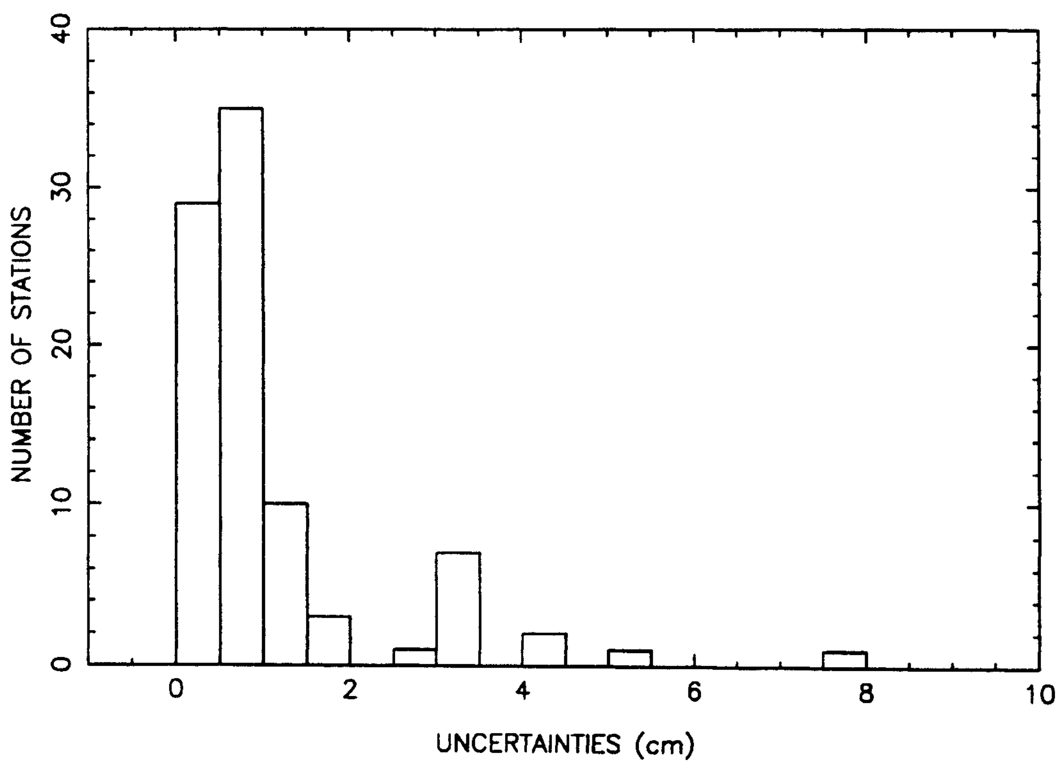
The EOP series that are attached to this submission were "Vondrak"smoothed using an epsilon value of 0.1 . The reason for the smoothing was the elimination of some spurious values due to lack of observations during the averaging interval. This only occured at a few instances, about 4% of the data have been edited in this fashion. The smoothing replaces these aberrant values with interpolated values based on those before and after the spurious point. The LODR series were obtained from the forward differencing of the UT1R series with IERS-nodes at arc-length intervals. The differencing was performed on the weakly smoothed UT1R series to minimize the noise amplification. Examination of the rms differences between the raw and the smoothed series indicates that given the accuracy of the series, the smoothing has not compromised its signal content.

**Summary description of the terrestrial system attached to the set of station coordinates SSC(GSFC) 92 L 01**

| | |
|---|---|
| 1 - Technique : | SLR to LAGEOS |
| 2 - Analysis Center : | NASA/GSFC |
| 3 - Solution Identifier : | GSFC SL8.1 |
| 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 : | SL7.1 and NUVEL-1NNR |
| 8 - Velocity of light : | 299792458 m/s |
| 9 - GM : | 398600.4415 km3/s2 |
| 10- Reference epoch : | 86 07 01 |
| 11- Adjusted Parameters - Orbit: | 6 elements every 30(35) days |
| | along track accel. every 15 days |
| | once per rev. accel. every 15 days |
| Stations: | estimated in three dimensions except lat., long. 7105 and lat. 7210 |
| EOP: | X,Y,UT1 every 5 days from 80 01 01 to 82 12 28 |
| | every day from 82 12 29 to 91 12 31 |
| | 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 : | SL7.1 and NUVEL-1NNR plate motion models the EOP values |




Distribution of the 65 sites of the terrestrial frame SSC(GFSC) 92 L 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 90 stations of the terrestrial frame SSC(GFSC) 92 L 01. 1 station with uncertainty larger than 10 cm is not shown.

EOP(GSFC) 92 L 01 From Jan 1980 to Dec 1991

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 | 0.37 | 74 | 0.22 | 61 | 0.30 |
| 1981 | 73 | 0.37 | 73 | 0.22 | 61 | 0.30 |
| 1982 | 75 | 0.31 | 75 | 0.22 | 63 | 0.30 |
| 1983 | 365 | 0.54 | 365 | 0.45 | 338 | 0.60 |
| 1984 | 366 | 0.37 | 366 | 0.32 | 354 | 0.50 |
| 1985 | 365 | 0.35 | 365 | 0.30 | 349 | 0.40 |
| 1986 | 365 | 0.37 | 365 | 0.31 | 349 | 0.40 |
| 1987 | 365 | 0.31 | 365 | 0.29 | 350 | 0.50 |
| 1988 | 366 | 0.32 | 366 | 0.31 | 355 | 0.40 |
| 1989 | 365 | 0.33 | 365 | 0.31 | 347 | 0.40 |
| 1990 | 365 | 0.34 | 365 | 0.38 | 342 | 0.60 |
| 1991 | 364 | 0.42 | 364 | 0.42 | 339 | 0.50 |

# A 7.8-YEAR EARTH ROTATION FROM LAGEOS LASER RANGING NAL 92 L 01

M. Murata, National Aerospace Laboratory, Tokyo

The set of solution for earth orientation parameters and station coordinates was derived by fitting 30-day arcs of LAGEOS normal points for the period of September 1983 through May 1991. Models and constants adopted adhere to the IERS Standards. The 94 30-day arcs were combined to form a unique solution for the six cartesian orbital elements at every arc epoch, two coefficients of along-track accerelation (every 15 days), three coefficients of solar radiation pressure (every 10 days), earth orientation parameters (every 5 days), and station coordinates (over the whole interval). The overall post RMS fit of the laser normal points to the orbits in 30-day arcs ranged 6 to 13 cm.

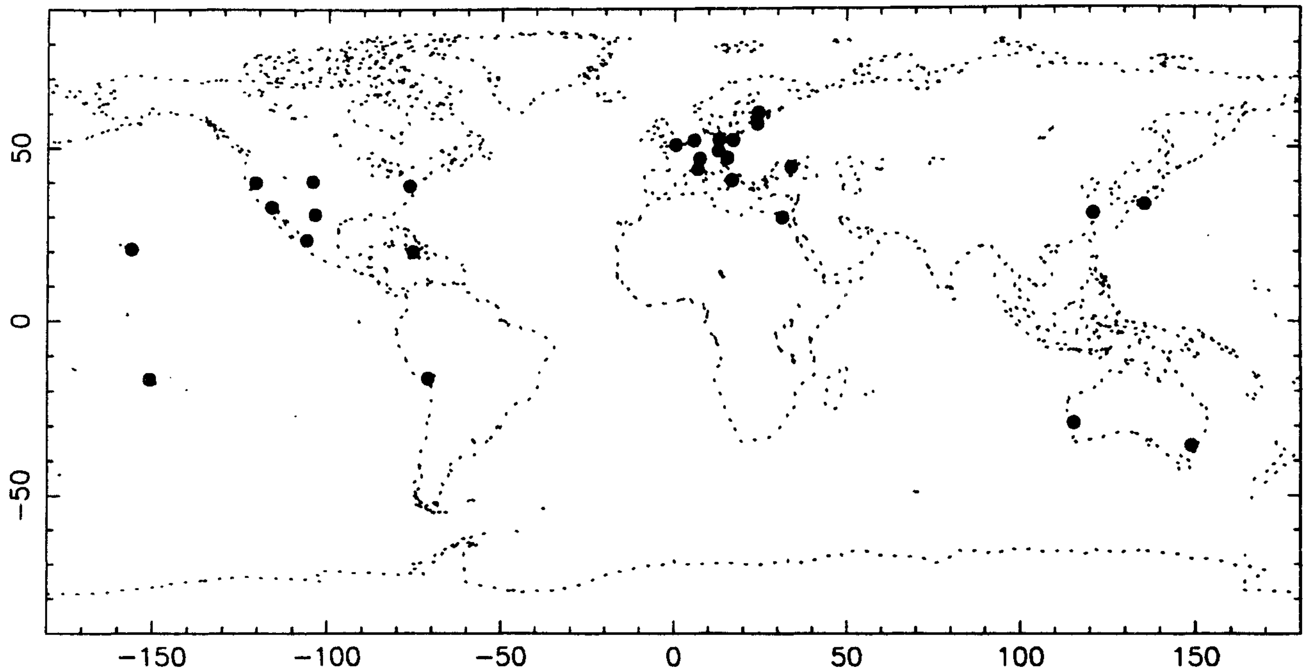
The station coordinate SSC(NAL) 92 L 01 includes solutions for the selected 30 stations which tracked LAGEOS with longer data coverage over the 7.8-year interval, and it has the reference epoch on 1990 January 1 0h UTC assuming the Minster-Jordan plate motion model AM0-2. The origin of the reference system was defined by fixing the longitude and latitude of station 7105 (Greenbelt) and the latitude of station 7909 (Arequipa). Corrections due to the permanent tidal deformation of the earth were applied.

The estimation strategy of earth orientation parameters is that pole coordinates are assumed constant over each 5-day subarc and UT1R-TAI is assumed to be continuous and piecewise linear over each subarc so that only values at subarc nodes, except for the epochal value which is kept fixed at that taken from the IERS Bulletin B, need to be estimated. The excess length of day is derived straightforwards using this model.

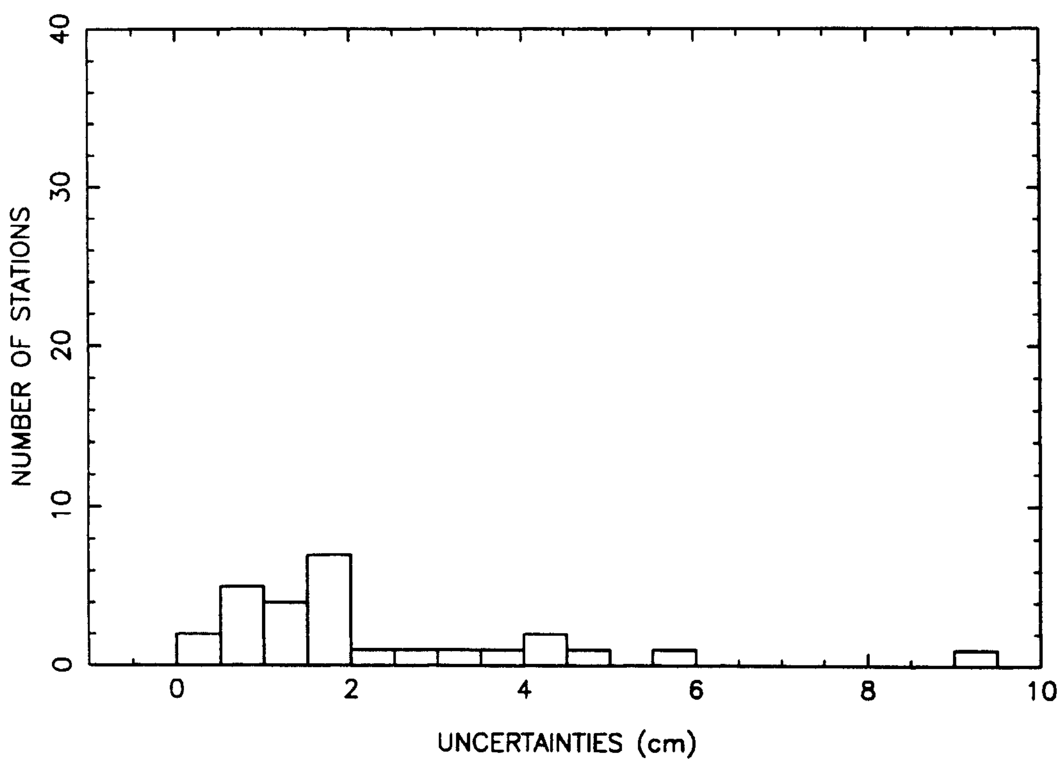
The earth orientation parameter series for the 7.8-year interval, designated as EOP(NAL)92 L 01, and the station coordinates at the reference epoch (January 1, 1990) are available on request from the Central Bureau of IERS. The coordinates refer to the optical axis of the laser ranging system.

## Summary description of the terrestrial system attached to the set of station coordinates SSC(NAL) 92 L 01

| | |
|---|---|
| 1 - Technique : | SLR |
| 2 - Analysis Center: | NAL |
| 3 - Solution identifier : | SSC(NAL) 92 L 01 |
| 4 - Software used : | COSMOS |
| 5 - Relativity Scale : | LE |
| 6 - Permanent tidal correction on station : | NO |
| 7 - Tectonic plate model: | AM0-2 |
| 8 - Velocity of light : | 299792458 m/sec |
| 9 - Geogravitational constant (GM0) : | 398600.4415 km3/s2 (fixed) |
| 10 - Reference epoch : | 1 January 1991 (MJD 48257.0) |
| 11 - Adjusted parameters : | 6 Cartesian elements (for each 30-day arc) ; CR (for 10 days); CA (for 15 days) ; PX, PY, UT1R (for 5 days) ; Station coordinates (globally adjusted) |
| 12 - Definition of the origin : | C10=C11=S11=0 |
| 13 - Definition of the orientation : | Two latitudes and one longitude |
| 14 - Constraint for time evolution : | Fixed plate motion model |




Distribution of the 27 sites of the terrestrial frame SSC(NAL) 92 L 01.




Distribution of the uncertainties (quadratic mean of $\sigma_x$, $\sigma_y$, $\sigma_z$) for the 28 stations of the terrestrial frame SSC(NAL) 92 L 01. 1 station with uncertainty larger than 10 cm is not shown.

EOP(NAL) 92 L 01 From Sep 1983 to May 1991

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

| YEAR | X | | Y | | D | |
|---|---|---|---|---|---|---|
| | Nb | Sigma | Nb | Sigma | Nb | Sigma |
| 1983 | 25 | 0.80 | 25 | 0.40 | 25 | 0.22 |
| 1984 | 73 | 0.80 | 73 | 0.40 | 73 | 0.19 |
| 1985 | 73 | 0.80 | 73 | 0.40 | 73 | 0.16 |
| 1986 | 73 | 0.80 | 73 | 0.40 | 73 | 0.18 |
| 1987 | 73 | 0.80 | 73 | 0.40 | 73 | 0.18 |
| 1988 | 73 | 0.80 | 73 | 0.40 | 73 | 0.17 |
| 1989 | 73 | 0.80 | 73 | 0.40 | 73 | 0.23 |
| 1990 | 73 | 0.80 | 73 | 0.40 | 73 | 0.21 |
| 1991 | 28 | 0.90 | 28 | 0.50 | 28 | 0.28 |

# COMBINATION

# A COMBINATION OF EARTH ORIENTATION DATA: SPACE91 JPL 91 C 01

R. S. Gross - Jet Propulsion Laboratory, California Institute of Technology,
Pasadena, CA 91109-8099, USA

A combination of independently-determined Earth orientation data has been generated from space-geodetic observations spanning 1976-1991. 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), and lunar laser ranging (LLR) 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, private communication, 1991) and only one SLR data set was used, namely, that determined at the University of Texas Center for Space Research (UTCSR; Eanes, private communication, 1991; note that the SLR UT1 results were not used herein 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). Three different data sets derived from independent VLBI observations have been used: the approximately twice-a-week single baseline measurements made using the radio telescopes of NASA's Deep Space Network (DSN; Steppe, private communication, 1992), 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. 96, February, 1992; both their multibaseline results at about 5-day intervals and their Intensive UT1 results at daily intervals have been used), and 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 observations and from the CDP reduction of the IRIS multibaseline observations (Ma, private communication, 1991). Note that both the IRIS and CDP series used here include UTPM values determined by their own respective reductions of data taken by the United States Naval Observatory (USNO). Again, since it was desirable to combine only independent UTPM determinations, no series derived at the USNO was used (since the USNO data are reduced by, and the results included in, the IRIS and CDP series), and the results of the CDP reduction of the IRIS and USNO observations were used during 1979-1990, with the IRIS multibaseline series being used from 1991 onwards (all of the IRIS Intensive results were used, however).

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 Brosche *et al.* (1989) was used to remove the effect of the long period (fortnightly and longer) oceanic tides upon UT1 [the Brosche *et al.* (1989) oceanic corrections to the Yoder *et al.* (1981) results were actually removed (Williams, private communication, 1992)]. Finally, the model of Brosche *et al.* (1989) was also used to remove the effect of the semi-diurnal and diurnal oceanic tides upon those UT1 values that were determined from observations spanning a short enough time interval that these tidal effects should be present in them (namely, the LLR, DSN and IRIS Intensive series). The IRIS Intensive UT1 values are determined from observations spanning a short enough time interval that the semi-diurnal and diurnal oceanic tidal terms should be present at essentially full amplitude. However, the LLR and DSN observations span a long enough time interval that the semi-diurnal and diurnal oceanic tidal terms will be attenuated. Thus, for the LLR and DSN series, an attenuated version of the Brosche *et al.* (1989)

semi-diurnal and diurnal oceanic tidal terms was removed. The attenuation factor applied depends upon the frequency (w) of the tidal term, as well as the duration time (T) of the observations (e.g. Guinot, 1970) and is given by [sin(wT/2)]/[wT/2].

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 fashion wherein each data set was compared to a combination of all other data sets (except for the IRIS multibaseline series which was treated separately as described below). First, a reference series (an extension of SPACE90) was used to initially correct the bias and rate of each 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 series was iteratively adjusted 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 the series were then applied 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 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 111 data points, or about two percent of the available data points, were thus deleted from all the series.

A bias-rate correction and uncertainty scale factor was determined for the IRIS multibaseline series by comparing this series 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 determined for them in the above iterative, round-robin procedure. For the purpose of this comparison, only the non-IRIS results contained in the CDP multibaseline series were selected and used. Also, for the purpose of this comparison, the entire IRIS multibaseline series, starting in 1980, was used so that a rate correction could be determined for it. Thus, a bias-rate correction and uncertainty scale factor was determined for the IRIS multibaseline series based upon the entire data set, even though just the corrected values since 1991 ultimately get combined with the other series. 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 IRIS multibaseline data since 1991, 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 for the years 1984-1991 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 IRIS multibaseline 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 CDP single baseline 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 IRIS multibaseline series was not included in the iterative, round-robin procedure, the bias-rate correction given in Table 2 for this series is just the sum of the relative correction that was determined for it separately (see above) and the additional, common correction needed to place it within the IERS reference frame. The error in the bias-rate correction (given in parentheses in Table 2) is the formal error in determining the relative correction. The uncertainty scale factor given in Table 2 for the IRIS multibaseline series is just the scale factor determined for it separately as described above when comparing it to a combination 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 IRIS multibaseline results since 1991) after adjusting their biases, rates, and uncertainties by the amounts given in Table 2. This final combination, spanning May 24.0, 1976 to January 19.0, 1992, is designated SPACE91 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 Brosche *et al.* (1989) was used to add back the oceanic tidal corrections to the Yoder *et al.* (1981) results. No diurnal or semi-diurnal oceanic tidal terms were added back, so the UT1 values given in SPACE91 can be properly considered to be UT1-UTC. 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 SPACE91 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 0.3 mas in polar motion and 0.03 ms in UT1.

**Acknowledgements.** We would like to thank R. Eanes for providing us with the SLR data used in this study, C. Ma for the CDP data, X Newhall and J. Williams for the LLR data, and S. Oliveau, O. Sovers and A. Steppe for the DSN data. This study would not have been possible without their and their colleagues efforts in generating the UTPM series that they so generously provided to us. The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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Yoder, C. F., Williams, J.G. and Parke, M.E., 1981: Tidal variations in Earth rotation, *J. Geophys. Res.*, **86**, 881-891.

Table 1. Data combined

| DATA SET NAME | DATA TYPE | ANALYSIS CENTER | DATA SPAN | NUMBER POINTS | PLATE MODEL |
|---|---|---|---|---|---|
| LLR (91M01; VAR LAT, UT0) | | | | | |
| McDonald Cluster | LLR | JPL | 22MAY76-09DEC90 | 376 | AM0-2 |
| CERGA | LLR | JPL | 07APR84-26FEB91 | 281 | AM0-2 |
| Haleakala | LLR | JPL | 14NOV84-11AUG90 | 68 | AM0-2 |
| DSN (91R01; T, V) | | | | | |
| CA-Spain Cluster | VLBI | JPL | 26NOV79-06FEB92 | 371 | AM0-2 |
| CA-Australia Cluster | VLBI | JPL | 28OCT78-05FEB92 | 383 | AM0-2 |
| CDP (GLB716) | | | | | |
| Multibaseline | VLBI | GSFC | 04AUG79-08JAN91 | 934 | Adjusted |
| Westford-Ft. Davis | VLBI | GSFC | 25JUN81-01JAN84 | 103 | Adjusted |
| Westford-Mojave | VLBI | GSFC | 21MAR85-06AUG90 | 18 | Adjusted |
| UTCSR (91L03; PMX, PMY) | | | | | |
| LAGEOS | SLR | UTCSR | 15MAY76-19FEB91 | 1203 | Adjusted |
| IRIS (UT1MC05FEB92; UT1) | | | | | |
| Intensive | VLBI | NGS | 02APR84-25JAN92 | 1696 | Adjusted |
| ........................................ | | | | | |
| IRIS (IRIS31JAN92) | | | | | |
| Multibaseline | VLBI | NGS | 13JAN91-24JAN92 | 85 | Adjusted |

Table 2. Adjustments to data sets

| DATA SET NAME | BIAS (mas) | | RATE (mas/yr) | | UNCERTAINTY SCALE FACTOR | |
|---|---|---|---|---|---|---|
| LLR (91M01) | LAT | UT0 | LAT | UT0 | LAT | UT0 |
| McDonald Cluster | -0.297 | 6.464 | -0.780 | 0.272 | 1.013 | 1.083 |
| | (0.444) | (0.327) | (0.095) | (0.098) | | |
| CERGA | -2.426 | 1.728 | 0.373 | -0.247 | 1.271 | 1.194 |
| | (0.233) | (0.131) | (0.109) | (0.059) | | |
| Haleakala | 2.401 | 4.418 | 0.144 | -0.480 | 1.218 | 1.212 |
| | (0.376) | (0.265) | (0.239) | (0.174) | | |
| DSN (91R01) | T | V | T | V | T | V |
| CA-Spain Cluster | 1.508 | -1.247 | 0.159 | 0.201 | 1.111 | 1.051 |
| | (0.083) | (0.231) | (0.040) | (0.090) | | |
| CA-Australia Cluster | -2.939 | 1.963 | -0.396 | -0.143 | 1.179 | 1.107 |
| | (0.059) | (0.192) | (0.025) | (0.078) | | |

Table 2. Adjustments to data sets (cont.)

| DATA SET NAME | BIAS (mas) | | | RATE (mas/yr) | | | UNCERTAINTY SCALE FACTOR | | |
|---|---|---|---|---|---|---|---|---|---|
| CDP (GLB716) | | T | V | | T | V | | T | V |
| Westford-Ft. Davis | | -1.461 | 0.939 | | -0.124 | -0.126 | | 1.406 | 0.968 |
| | | (0.281) | (0.508) | | | | | | |
| Westford-Mojave | | -0.999 | 1.167 | | -0.137 | -0.096 | | 1.778 | 1.117 |
| | | (0.228) | (0.450) | | | | | | |
| CDP (GLB716) | PMX | PMY | UT1 | PMX | PMY | UT1 | PMX | PMY | UT1 |
| Multi | -0.714 | -1.356 | -0.766 | 0.059 | -0.133 | -0.296 | 1.415 | 1.314 | 1.433 |
| | (0.032) | (0.027) | (0.034) | (0.016) | (0.014) | (0.019) | | | |
| UTCSR (91L03) | PMX | PMY | UT1 | PMX | PMY | UT1 | PMX | PMY | UT1 |
| LAGEOS | 0.446 | -0.968 | --- | -0.020 | -0.383 | --- | 0.966 | 0.876 | --- |
| | (0.029) | (0.024) | | (0.015) | (0.013) | | | | |
| IRIS (05FEB92) | PMX | PMY | UT1 | PMX | PMY | UT1 | PMX | PMY | UT1 |
| Intensive | --- | --- | 1.092 | --- | --- | -0.177 | --- | --- | 0.980 |
| | | | (0.029) | | | (0.017) | | | |
| ........ | | | | | | | | | |
| IRIS (31JAN92) | PMX | PMY | UT1 | PMX | PMY | UT1 | PMX | PMY | UT1 |
| Multi | -10.010 | 3.748 | 1.117 | 0.131 | 0.192 | -0.153 | 1.460 | 1.428 | 1.405 |
| | (0.043) | (0.041) | (0.039) | (0.019) | (0.018) | (0.017) | | | |

Reference time for rate adjustment is 1988.0

EOP(JPL) 92 C 01 From May 1976 to Jan 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 |
| 1976 | 222 | 3.77 | 222 | 3.00 | 222 | 6.52 |
| 1977 | 365 | 2.81 | 365 | 2.11 | 365 | 4.49 |
| 1978 | 365 | 2.83 | 365 | 1.92 | 365 | 5.51 |
| 1979 | 365 | 2.35 | 365 | 1.83 | 365 | 4.10 |
| 1980 | 366 | 1.47 | 366 | 0.95 | 366 | 2.76 |
| 1981 | 365 | 1.30 | 365 | 0.94 | 365 | 1.95 |
| 1982 | 365 | 1.01 | 365 | 0.80 | 365 | 1.41 |
| 1983 | 365 | 0.86 | 365 | 0.75 | 365 | 1.08 |
| 1984 | 366 | 0.52 | 366 | 0.43 | 366 | 0.56 |
| 1985 | 365 | 0.44 | 365 | 0.37 | 365 | 0.35 |
| 1986 | 365 | 0.42 | 365 | 0.35 | 365 | 0.31 |
| 1987 | 365 | 0.35 | 365 | 0.29 | 365 | 0.30 |
| 1988 | 366 | 0.31 | 366 | 0.28 | 366 | 0.28 |
| 1989 | 365 | 0.30 | 365 | 0.26 | 365 | 0.27 |
| 1990 | 365 | 0.27 | 365 | 0.27 | 365 | 0.25 |
| 1991 | 365 | 0.48 | 365 | 0.40 | 365 | 0.30 |
| 1992 | 19 | 0.45 | 19 | 0.40 | 19 | 0.24 |

# COMBINATION OF PRECISE OBSERVATIONS OF THE ORIENTATION OF THE EARTH
NEOS 92 C 01

[The procedure for obtaining this series is described in the IERS Annual Report for 1991, part. III.]

EOP(NEOS) 92 C 01 From Sep 1980 to Mar 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 |
| 1980 | 96 | 2.44 | 96 | 2.10 | 96 | 1.98 |
| 1981 | 365 | 3.17 | 365 | 2.70 | 365 | 3.49 |
| 1982 | 365 | 3.29 | 365 | 2.86 | 365 | 2.76 |
| 1983 | 365 | 2.90 | 365 | 2.67 | 365 | 2.89 |
| 1984 | 366 | 1.68 | 366 | 1.45 | 366 | 1.21 |
| 1985 | 365 | 1.36 | 365 | 1.12 | 365 | 0.92 |
| 1986 | 365 | 1.37 | 365 | 1.09 | 365 | 0.80 |
| 1987 | 365 | 0.75 | 365 | 0.92 | 365 | 0.78 |
| 1988 | 366 | 0.82 | 366 | 1.18 | 366 | 0.69 |
| 1989 | 365 | 0.69 | 365 | 0.69 | 365 | 0.56 |
| 1990 | 365 | 0.72 | 365 | 0.68 | 365 | 0.57 |
| 1991 | 365 | 0.66 | 365 | 0.73 | 365 | 0.52 |
| 1992 | 66 | 0.46 | 66 | 1.00 | 66 | 0.64 |

# ATMOSPHERIC ANGULAR MOMENTUM

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

AAM(AER) 87 * 01

Deirdre M. Kann
Climate Analysis Center, National Meteorological Center, Washington, DC 20233
David A. Salstein
Atmospheric and Environmental Research, Inc., 840 Memorial Dr., Cambridge, MA 02139

## I. 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 1991. 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.

## II. 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 $\chi_1$, $\chi_2$, and $\chi_3$, 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 $\chi_3$ term. As a result of an earlier formulation, all NMC $\chi_3$ 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.

## III. 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 evaporation. 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 1991 IERS Annual Report.

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<br>20 wave, zonals only<br>with and without inverted barometer | (30)<br>(21)<br>(30)<br>(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) |

## References

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

Kanamitsu, M., 1989: Description of the NMC Global Data Assimilation and Forecast System, *Wea. Forecasting,* **4**, 335-342.

Mesinger, F., Janjic, Z.I., Nickovic, S., Gavrilov D., and Deaven, D.G., 1988: The step-mountain coordinate: Model description and performance for cases of Alpine lee cyclogenesis and for a case of an Appalachian redevelopment, *Mon. Wea. Rev.*, **116**, 1493-1518.

AAM(AER) 87 * 01 From 1976 to 1991

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

# EFFECTIVE ATMOSPHERIC ANGULAR MOMENTUM FUNCTIONS COMPUTED AT THE EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

AAM(ECMWF) 87 * 01

Klaus Arpe, European Centre for Medium-Range Weather Forecasts,
Shinfield Park, Reading, UK.

As reported in the *IERS Technical Note 2*, effective atmospheric angular momentum (EAAM) functions have continued to be calculated at ECMWF throughout 1991. The EAAM functions are calculated for the analyses every 6 hours and for forecasts from 12 UTC each day to 10 days (see Sakellarides, 1989). The inverted barometer terms are not calculated. The data are archived at ECMWF but are not supplied to the Sub-Bureau.

In May of 1989, ECMWF implemented changes in the cumulus convection and radiation schemes of its global model. The effect, if any, of these changes on the EAAM series is not known.

## References

Sakellarides, G., 1989: Atmospheric effective angular momentum functions for 1986-1987, *ECMWF Research Department Technical Report No. 62*.

AAM(ECMWF) 87 * 01 From 1986 to 1991

| Year | Number of Measurements |
|---|---|
| 1986 | 365 |
| 1987 | 365 |
| 1988 | 732 |
| 1989 | 730 |
| 1990 | 730 |
| 1991 | 62 |

# EFFECTIVE ATMOSPHERIC ANGULAR MOMENTUM FUNCTIONS COMPUTED FROM THE JAPAN METEOROLOGICAL AGENCY DATA AAM(JMA) 87 * 01

I.Naito, Y.Goto and N.Kikuchi,
National Astronomical Observatory, Mizusawa, Iwate, 023 Japan

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

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

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

**Acknowledgements**

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## References

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

Kanamitsu, M., Tada, K., Kudo, T., Sato, N., and Isa, S., 1983: Description of the JMA operational spectral model, *J. Meterol. Soc. Japan,* **61**, 812-828.

Kashiwagi, K., 1987: On the impact of space-based observing systems in the JMA global forecast/analysis system, *J. Meteorol. Soc. Japan,* **65**, 189-220.

Kitade, T.,1988: Numerical weather prediction in the Japan Meteorological Agency, *JMA/NPD Technical Report,* No.20.

Naito, I., Kikuchi N., and Yokoyama, K., 1987: Results of estimating the effective atmospheric angular momentum functions based on the JMA global analysis data, *Publ. Int. Latit. Obs. Mizusawa,* **20,** 1-11.

AAM(JMA) 87 * 01 From 1983 to 1991

| Year | Number of Measurements |
|---|---|
| 1983 | 150 |
| 1984 | 357 |
| 1985 | 365 |
| 1986 | 549 |
| 1987 | 730 |
| 1988 | 732 |
| 1989 | 730 |
| 1990 | 730 |
| 1991 | 730 |

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

Throughout 1991, 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.

**References**

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

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

AAM(UKMO) 83 * 01 From 1983 to 1991

| 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 | | |

Dépôt légal : 3ème trimestre 1992
Imprimeur : Observatoire de Paris

le Gérant : M. Combes