VERY LONG BASELINE INTERFEROMETRY

EARTH ORIENTATION PARAMETERS FROM IRIS-S VLBI MEASUREMENTS

GIUB 92 R 01
GIUB 92 R 02

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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, $\delta\psi$, $\delta\varepsilon$; 0.0001s for UT1

YEAR	X		Y		UT1		$\delta\psi$		$\delta\varepsilon$	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
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, $\delta\psi$, $\delta\varepsilon$; 0.0001s for UT1

YEAR	X		Y		UT1		$\delta\psi$		$\delta\varepsilon$	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
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

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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.

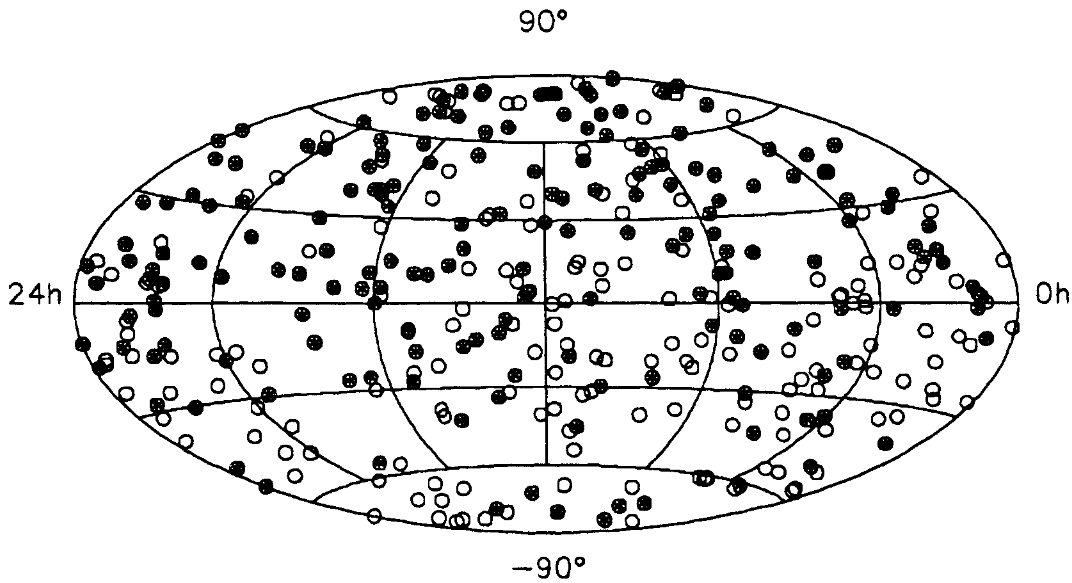
843523 dual-frequency Mark III delays and 23726 delay rates from 1677 sessions using fixed stations and mobile sites were combined to estimate site positions and velocities, source positions, Earth orientation parameters, and troposphere and clock behavior from a least-squares solution with 1309 global 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.

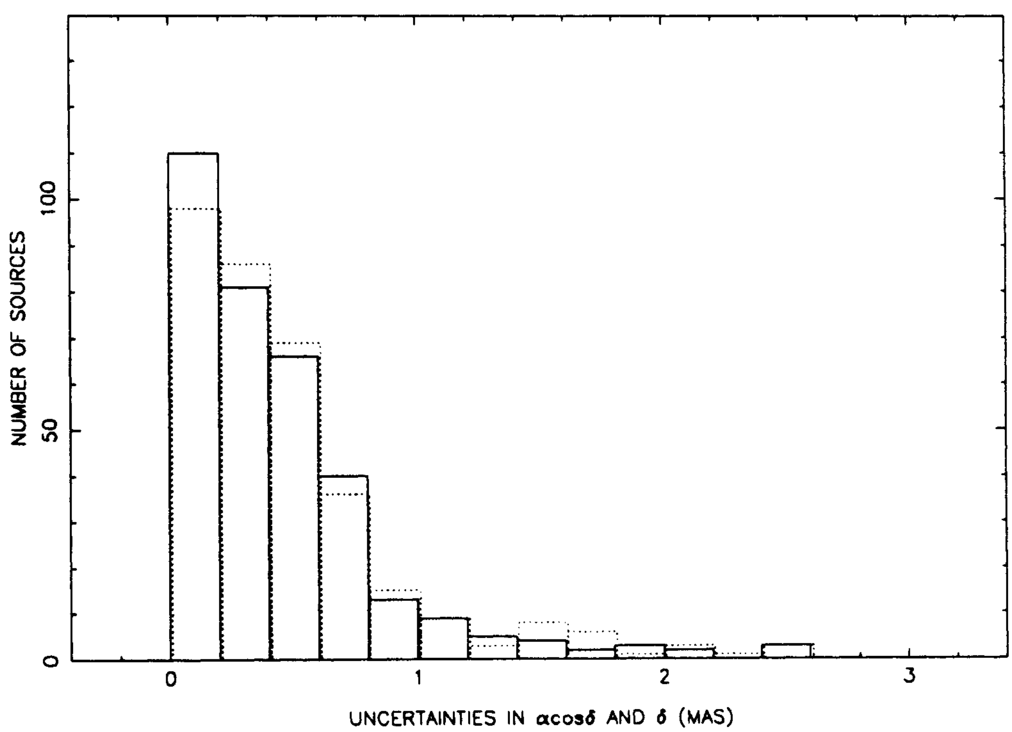
References

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

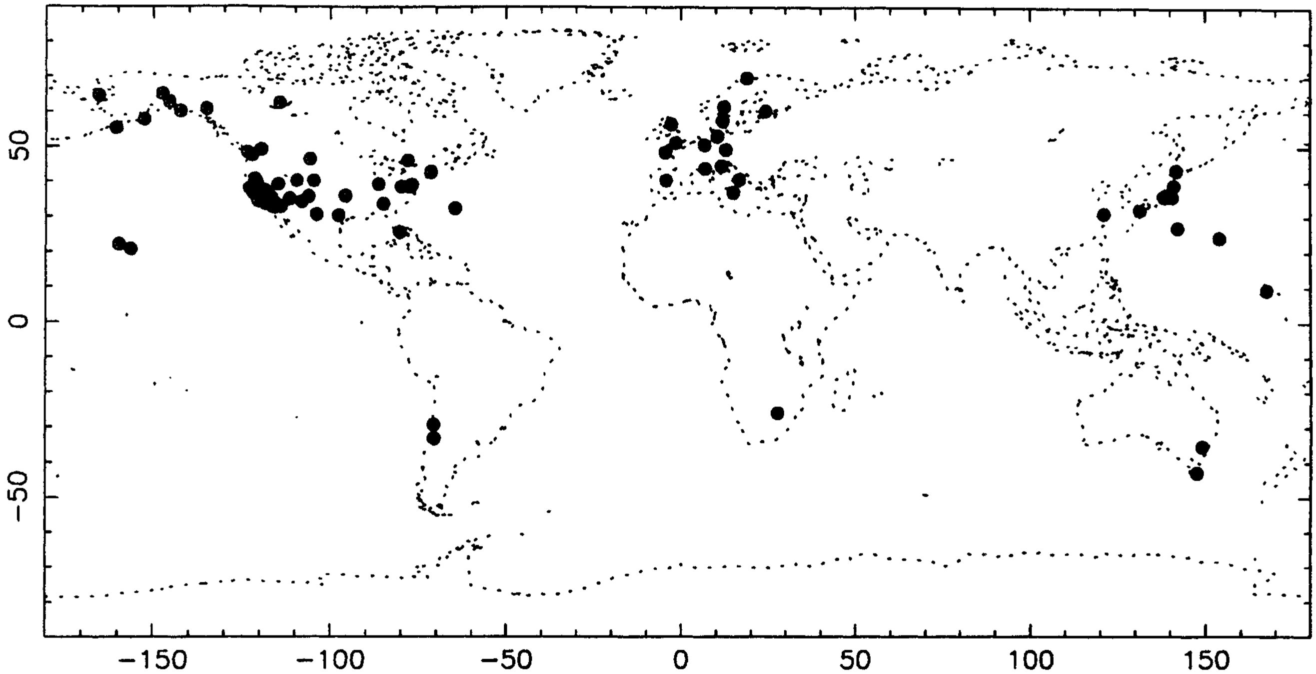
SUMMARY DESCRIPTION FOR SOLUTION GSFC 92 R 01: SEE P. 15



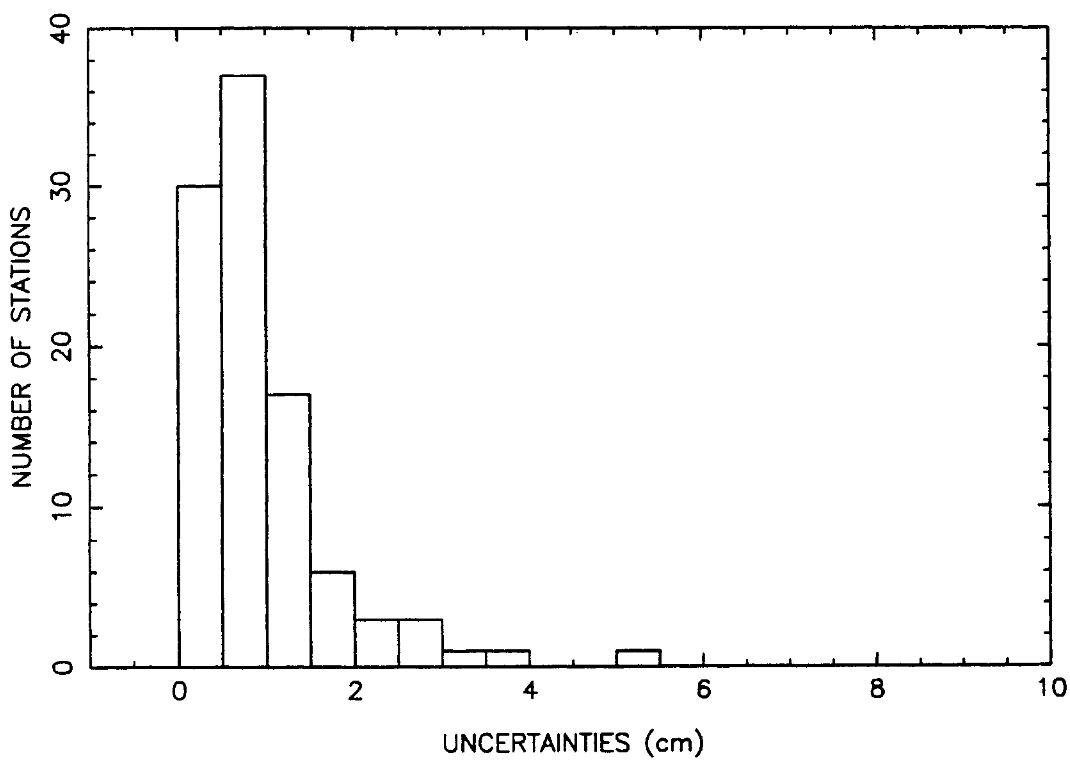
Distribution over the sky of the 357 extragalactic radio sources of the celestial frame RSC(GSFC) 92 R 01. Circles with asterisks indicate radio sources with uncertainties in right ascension ($\alpha\cos\delta$) and declination smaller than 0.0005".



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 σ_X, σ_Y, σ_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

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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

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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.

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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

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

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

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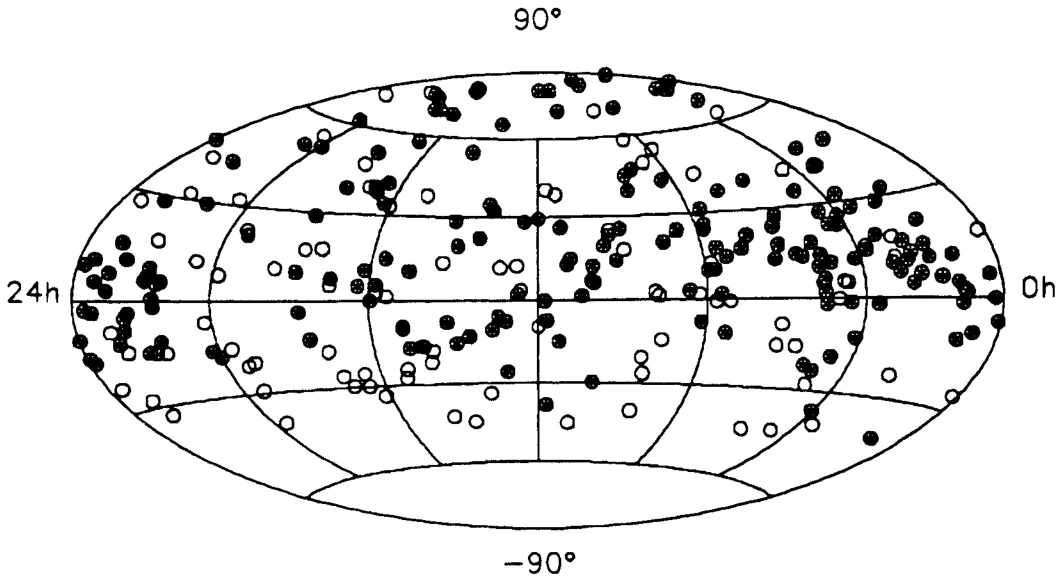
Summary description of the terrestrial system attached to the set of station coordinates SSC(JPL) 92 R 01.

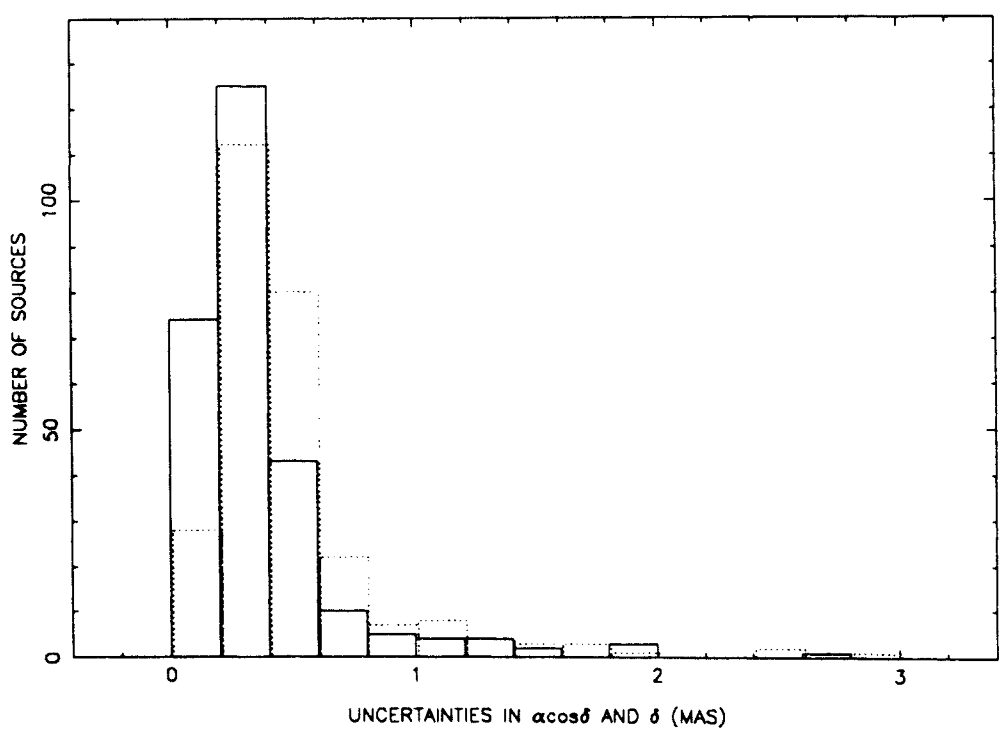
1 - Technique :	VLBI
2 - Analysis Center :	JPL
3 - Solution identifier :	1992-1
4 - Software used :	MODEST (nee Masterfit)
5 - Relativity scale :	LE (TDT = geocentric with IAT)
6 - Permanent tidal correction :	No
7 - Tectonic plate model :	AM0-2
8 - Velocity of light :	299 792 458 m/s
9 - Geogravitational 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.

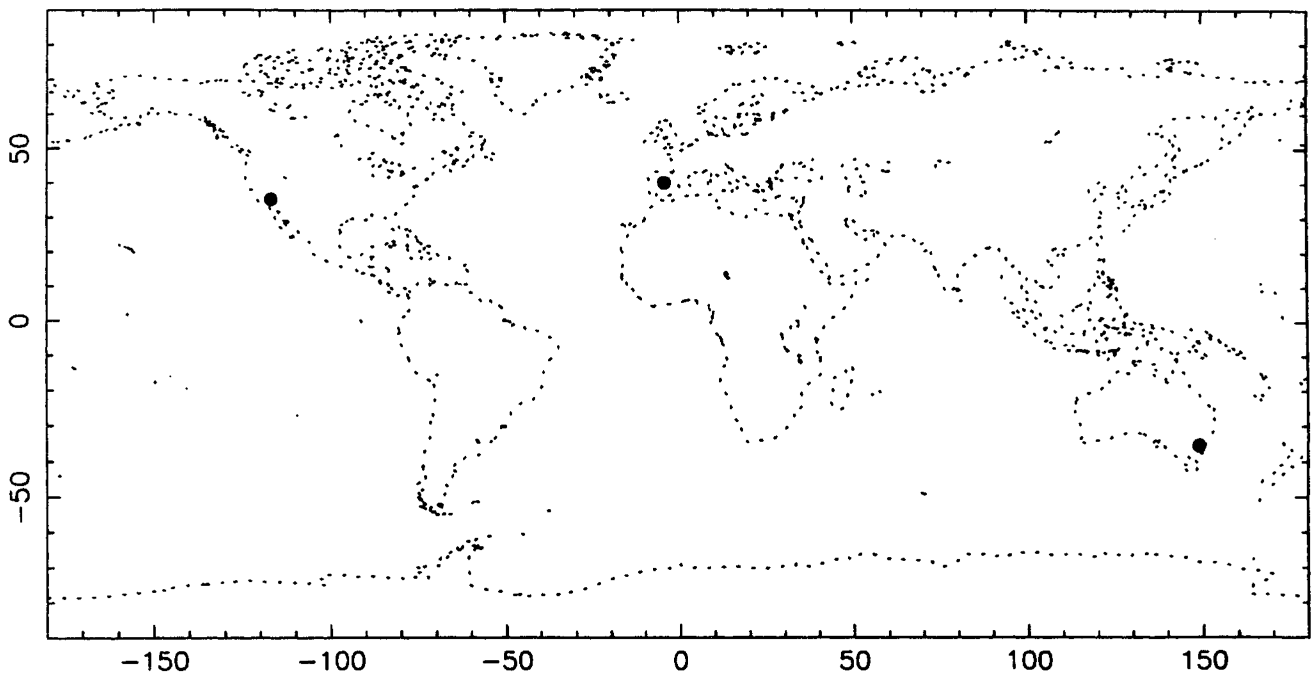
14 - Constraint for time evolution : AM0-2 model.



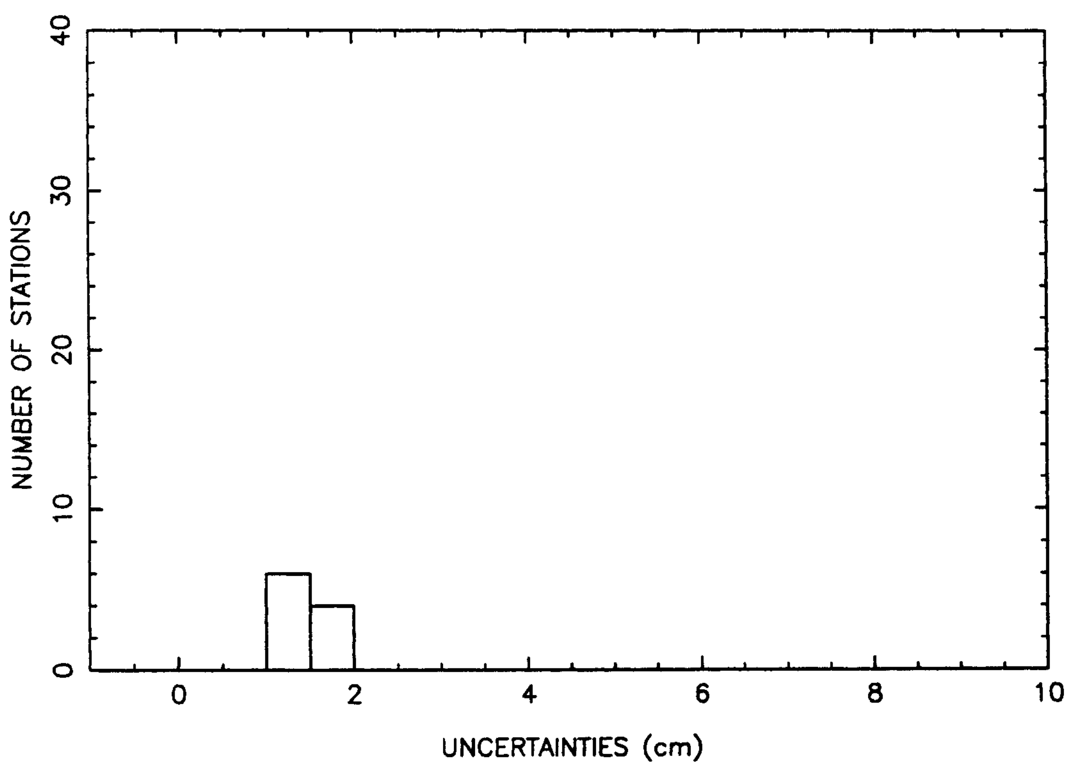
Distribution over the sky of the 282 extragalactic radio sources of the celestial frame RSC(JPL) 92 R 01.Circles with asterisks indicate radio sources with uncertainties in right ascension (αcosδ) and declination smaller than 0.0005".



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 σ_x, σ_y, σ_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

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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.

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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.

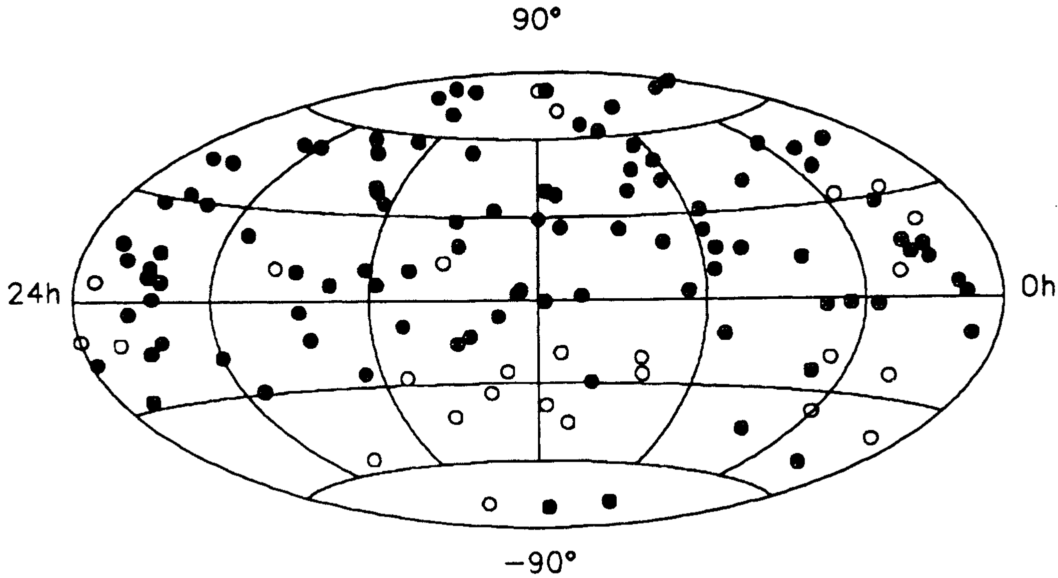
Relativistic time delay	: Fukushima(1991) with DE200 as planetary ephemerides.
Solid earth tide	: Cartwright, Taylor and Edden expansion of the tidal potential. The permanent tide is taken into account. The frequency dependent love numbers by Wahr (1981) are used in the diurnal band.
Ocean tidal loading	: 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

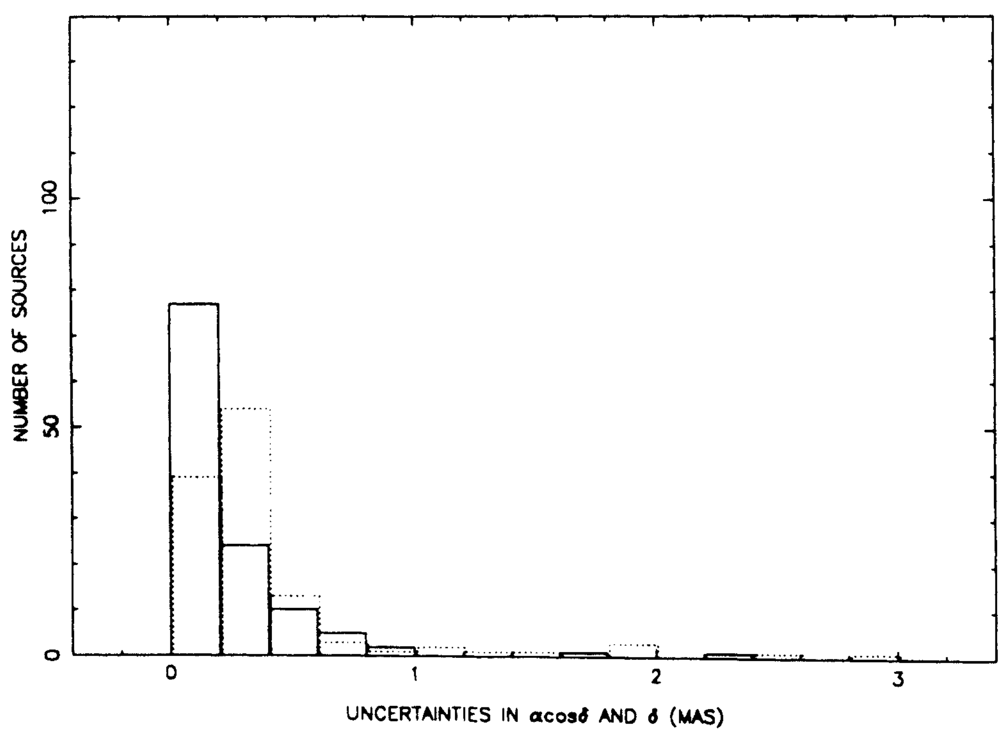
The coordinates of WESTFORD are fixed to those in ITRF90 and assumed to move along with AM0-2 plate motion. The mean orientation of GILCREEK, NRAO85 3, MOJAVE12, HRAS 085, WETTZELL, RICHMOND, WESTFORD, KAUAI, KASHIMA and ONSALA60 is fixed to ITRF90 at Jan. 1, 1988 and assumed to move along with AM0-2. 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

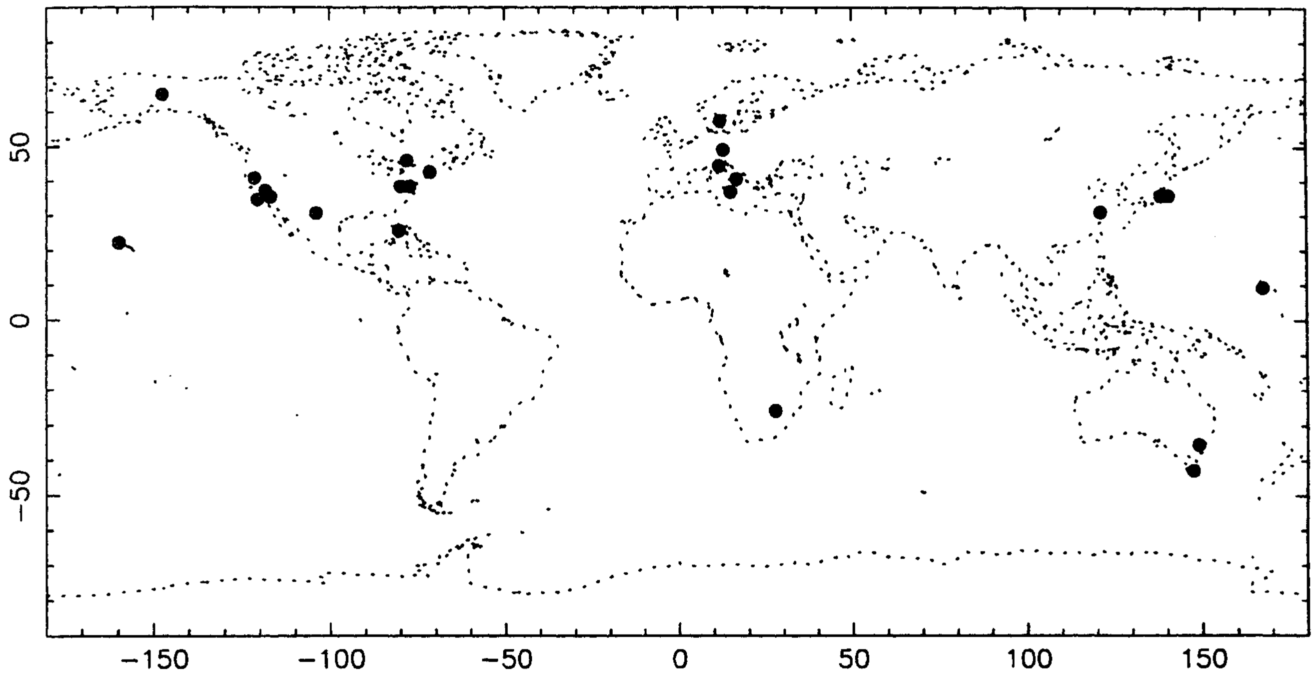
In the first step individual databases are analysed separately. Epochs and degrees of clock polynomials are determined. Tukey's M-estimate is used and weights automatically assigned with this method are used in the later global analysis. In the second step all the databases are treated as if they consist 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.



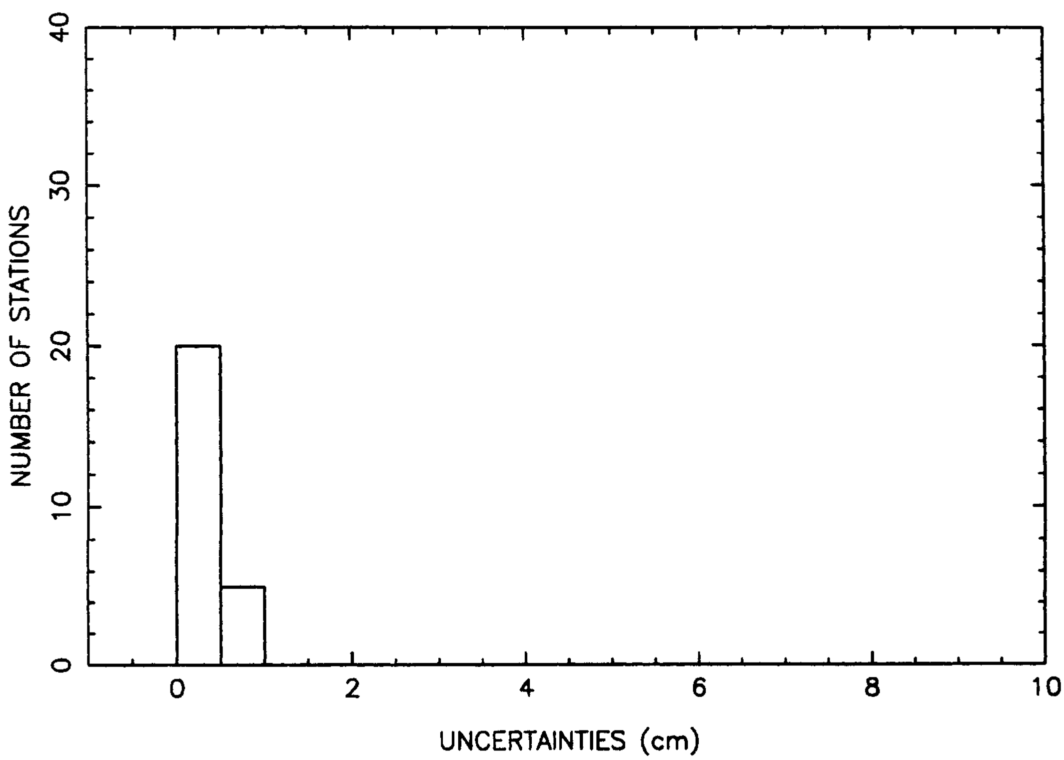
Distribution over the sky of the 125 extragalactic radio sources of the celestial frame RSC(NAOMZ) 92 R 01. Circles with asterisks indicate radio sources with uncertainties in right ascension ($\alpha\cos\delta$) and declination smaller than 0.0005".



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 σ_x, σ_y, σ_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,$\delta\psi$,$\delta\epsilon$; 0.0001s for UT1

YEAR	X		Y		UT1		$\delta\psi$		$\delta\epsilon$	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
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

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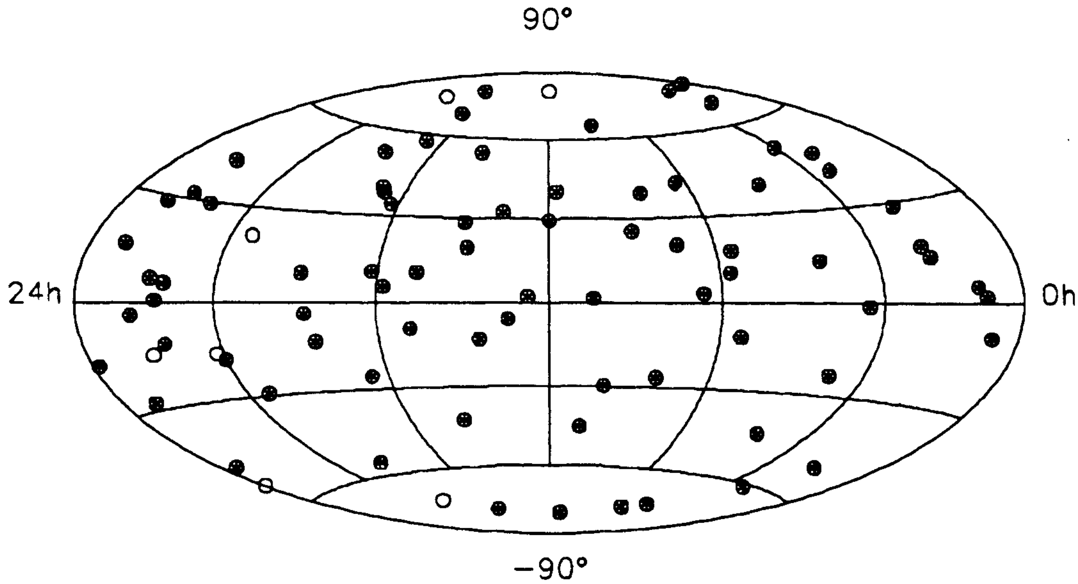
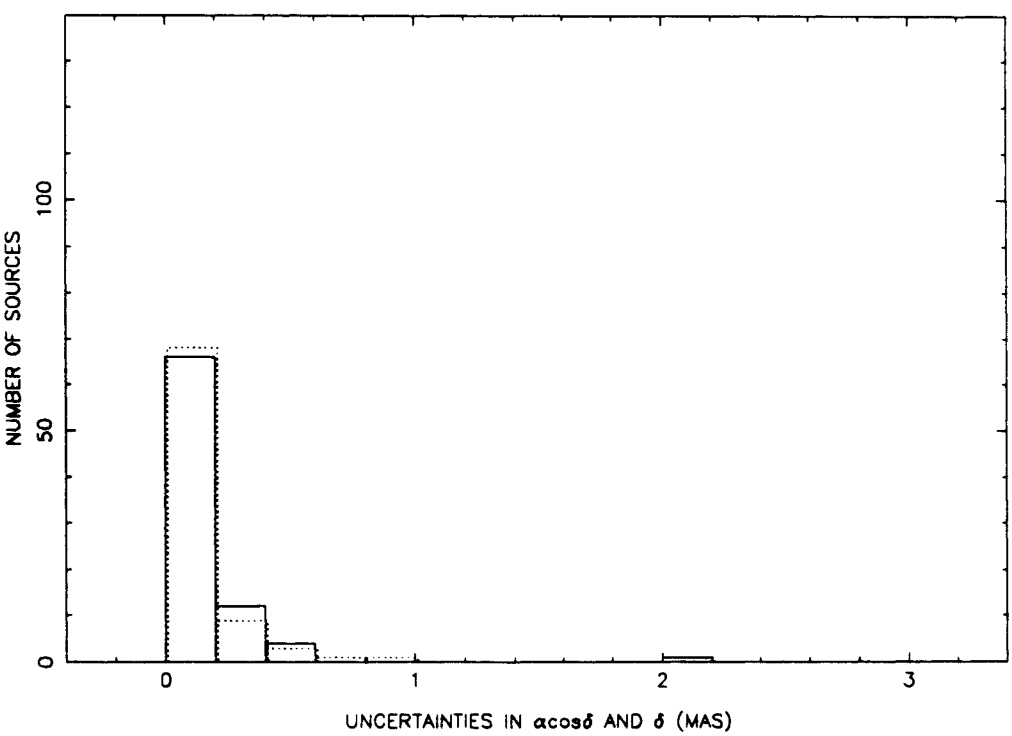
Summary description of the terrestrial system attached to the set of station coordinates SSC(NOAA) 92 R 01

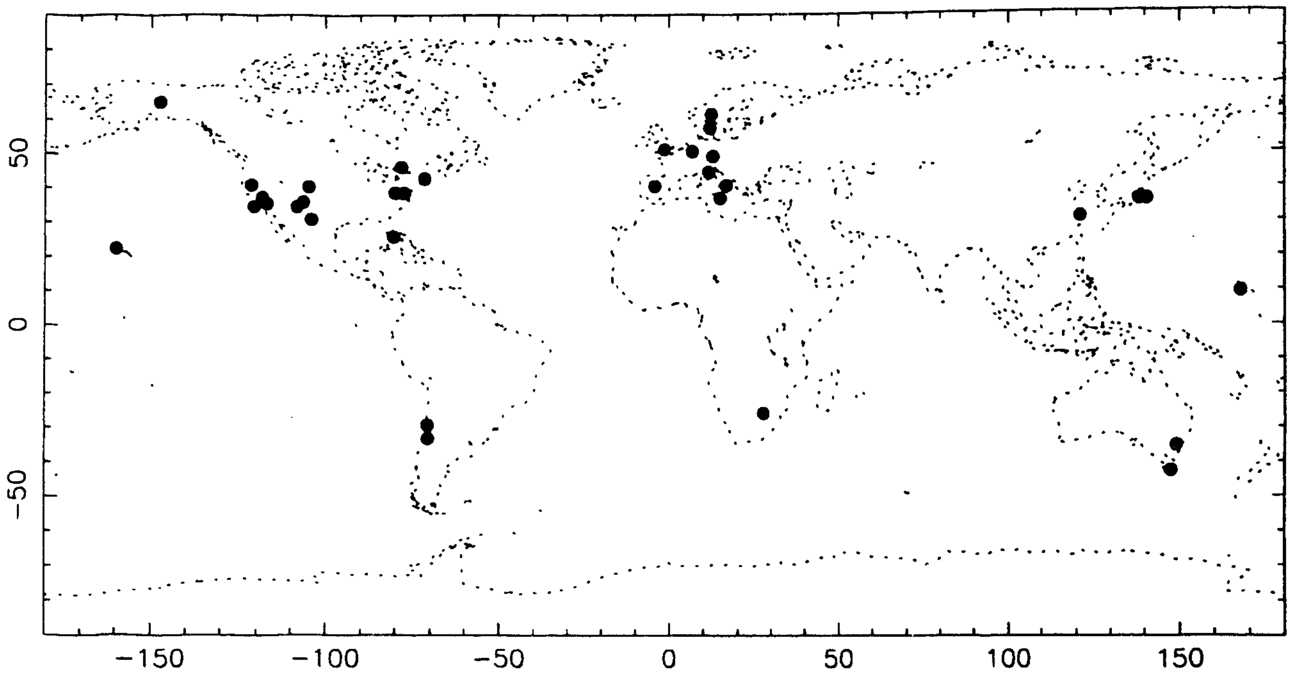
1 - Technique:	VLBI
2 - Analysis Center:	NOAA
3 - Solution Identifier:	SSC(NOAA) 92 R 01
4 - Software Used:	CALC
5 - Relativity Scale:	SSB
6 - Permanent Tidal Correction on Station:	Yes
7 - Tectonic Plate Model:	AM0-2, with station velocities adjusted
8 - Velocity of Light:	299792458
9 - Geogravitiational 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.



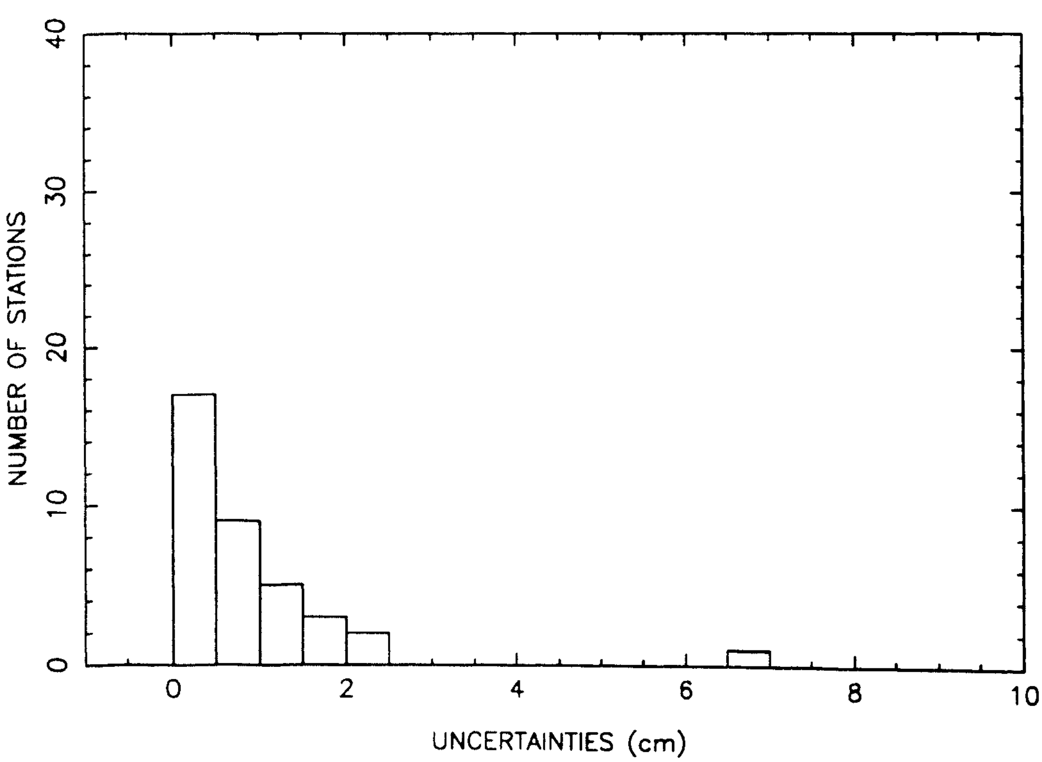
Distribution over the sky of the 84 extragalactic radio sources of the celestial frame RSC(NOAA) 92 R 01. Circles with asterisks indicate radio sources with uncertainties in right ascension (αcosδ) and declination smaller than 0.0005".



Distribution of the uncertainties in right ascension (full line) and declination (dashed line) of the celestial frame RSC(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 σ_x, σ_y, σ_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

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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

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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.

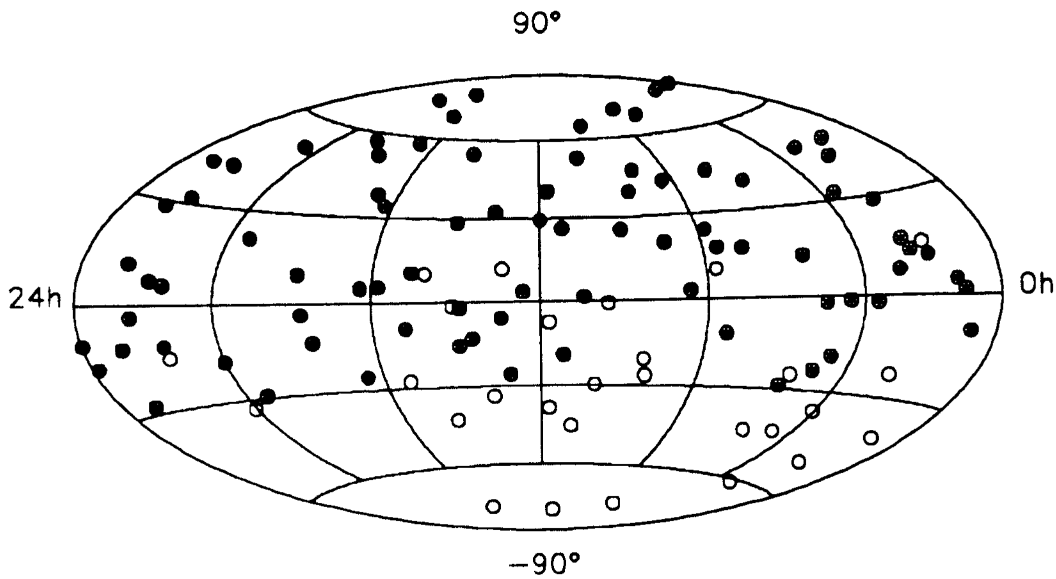
The errors presented in this report are formal errors obtained from the covariance matrix of the least squares adjustment. The post fit residual scatter is always larger than would be expected given the formal error estimates for the delay and delay rate observables provided by the correlator. The total 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

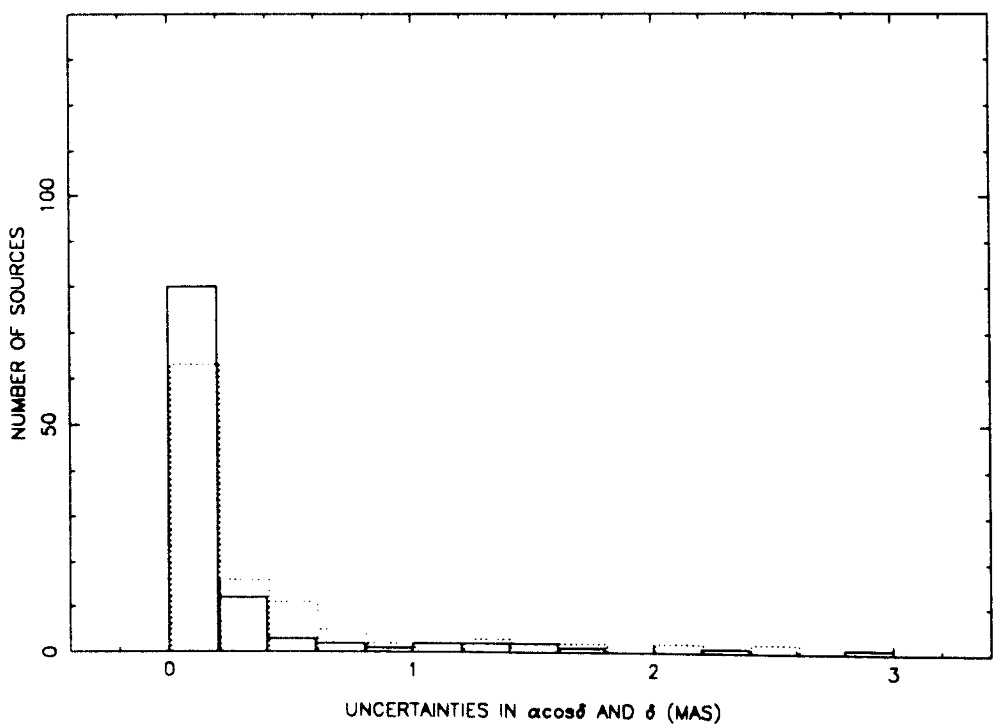
Questions, comments or requests to be placed on the NAVNET distribution list should be directed to T.M. Eubanks, Code TSEO, U.S. Naval Observatory, Washington D.C. 20392-5100, by phone at (202) 653-1501, on SPAN at CDDIS::USNO or USNO01::TME, and on Internet at tme@casa.usno.navy.mil or tme@usno01.usno.navy.mil.

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

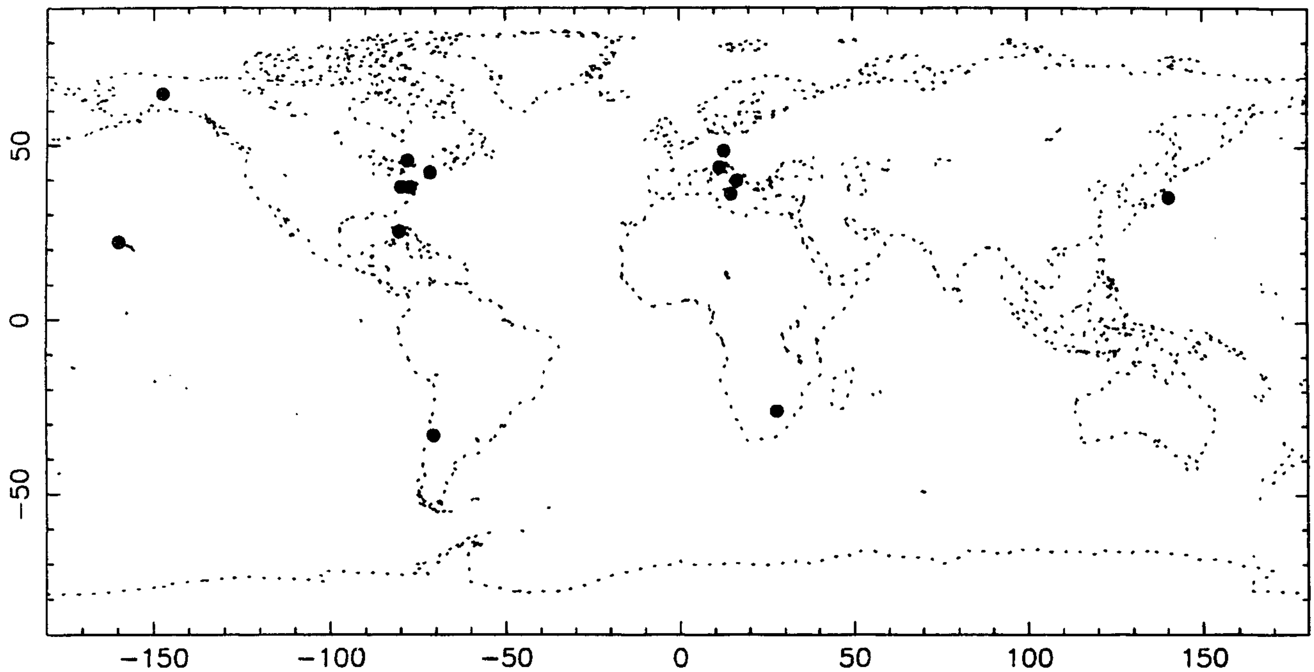
1 - Technique :	VLBI
2 - Analysis Center :	USNO
3 - Solution identifier :	SSC(USNO) 92 R 03 (USNO 1992-3)
4 - Software used :	Calc 7.6
5 - Relativity scale :	Geocentric
6 - Permanent tidal correction :	No
7 - Tectonic plate model :	Nuvell
8 - Velocity of light :	299 792 458 m/s
10 - Reference epoch :	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 Mean IERS Bull. A values for UT1, Polar and (indirectly) Nutation
14 - Constraint for time evolution :	Nuvell model



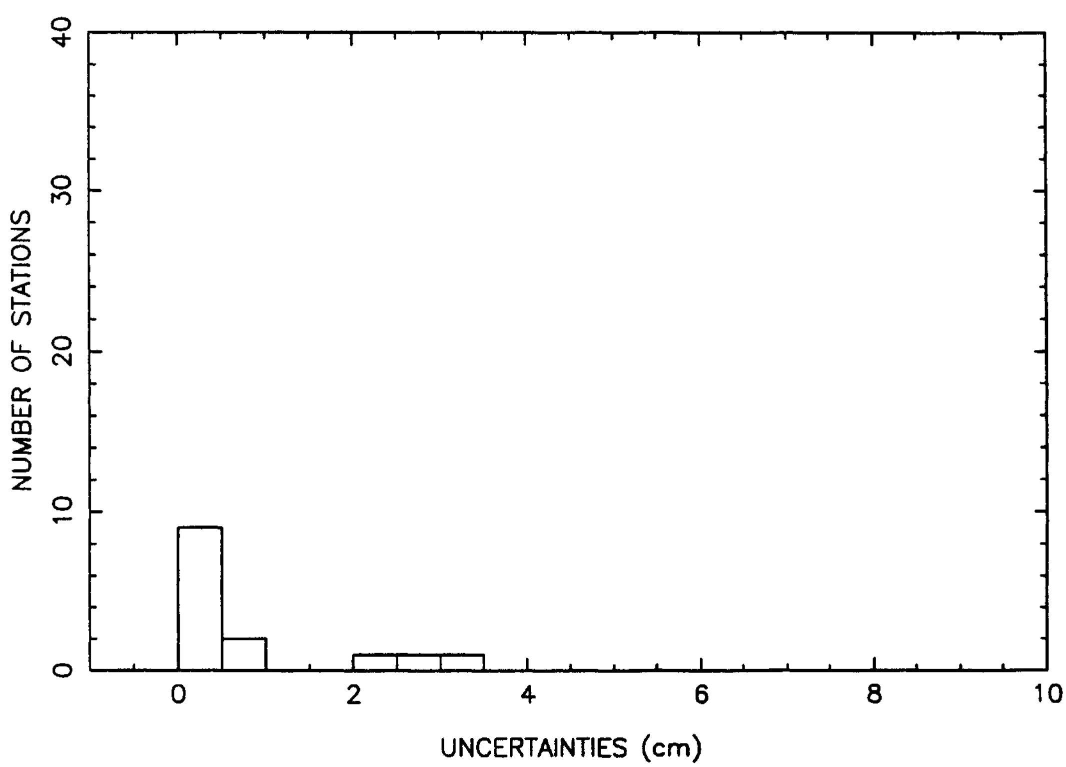
Distribution over the sky of the 113 extragalactic radio sources of the celestial frame RSC(USNO) 92 R 03. Circles with asterisks indicate radio sources with uncertainties in right ascension (αcosδ) and declination smaller than 0.0005".



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 σ_x, σ_y, σ_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, $\delta\psi$, $\delta\epsilon$; 0.0001s for UT1;

YEAR	X		Y		UT1		$\delta\psi$		$\delta\epsilon$	
	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma	Nb	Sigma
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