EARTH ORIENTATION FROM VLBI DURING SEARCH'92

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ABSTRACT. 66 VLBI sessions suitable for measuring Earth orientation parameters were conducted during SEARCH'92 including normally scheduled programs and a special continuous period with simultaneous networks between July 27 and August 10, inclusive. 53491 group delay observations from 24 stations spanned 1372 hours with 240 hours of overlapping networks. Both one-day and hourly Earth orientation values have been estimated. The best 1σ formal errors of the one-day values are 90 μas in pole and 4 μs for UT1, and the best corresponding errors of the hourly values are 140 μas and 8 μs.

1. INTRODUCTION

Since its inception in 1980, geodetic VLBI measurements to monitor Earth orientation parameters (EOP) have provided the stable reference series for geophysical and geodynamical research. The connection of VLBI to the essentially inertial celestial reference frame of extragalactic radio sources provides the key link for the long term measurement of UT1, while the precision of VLBI permits estimates of EOP at intervals much less a day. During SEARCH'92 a particular effort was made to collect as much useful VLBI data as feasible for the purposes of comparison and investigation of subdiurnal harmonic and nonharmonic signals. The cooperation of the coordinating organizations and participating observatories was essential to achieve this goal.

2. OBSERVING PROGRAMS

During the SEARCH'92 period the groups engaged in VLBI geodesy conducted an unusually extensive set of observations. These included the routine twice-weekly EOP measurements using the IRIS-A and NAVNET networks coordinated by NOAA (National Oceanic and Atmospheric Administration) and USNO (U. S. Naval Observatory), respectively, and the monthly EOP sessions using the IRIS-S(outh), IRIS-P(acific), and SHS (Southern Hemisphere Survey) networks coordinated by the Institute for Applied Geodesy (Germany), National Astronomical Observatory (Japan), and NOAA, respectively. The Space Geodesy Program (SGP) of the National Aeronautics and Space Administration had its regular monthly R&D sessions to test advances in geodetic VLBI technique as well as several sessions to improve the terrestrial reference frame. In addition, mobile VLBI measurements were made in Germany, Norway and Iceland with networks including stations in North America. In support of SEARCH'92 special sessions using the SGP R&D and the USNO NAVEX (NAVy EXtended) networks were scheduled to fill the gaps between the normal IRIS-A and NAVNET days in the period from July 27 to August 10. The SGP network used the stations KAUAI (Hawaii), GILCREEK (Alaska), LA-VLBA (New Mexico), FD-VLBA (Texas), WESTFORD (Massachusetts), and WETTZELL (Germany), while the NAVEX networks included MATERA (Italy), HARTRAO (South Africa), KASHIMA (Japan), NRAO85 3 (West Virginia), and SANTIA12 (Chile). The 66 dates, session types, and stations are shown in Table 1. Each session was ~24 hours or more. Eleven other sessions during SEARCH'92 used networks unsuitable for measuring EOP and were not included in the work below. Most of the SGP R&D and USNO NAVEX time between July 27 and August 10 overlapped. With six other days of simultaneous networks, the total overlapping time during SEARCH'92 was 240 hours. In all 1372 hours (61%) of the total SEARCH'92 interval was covered by VLBI observations.

The observing schedules for each SGP and NAVEX session were prepared using an automatic schedule algorithm developed at the Geodetic Institute of the University of Bonn and enhanced at Goddard. The software permits both covariance optimization and rule-based selection. The schedules were optimized for measuring EOP and atmosphere parameters while having a wide distribution of observing geometry at each station. The SGP observations were distributed quite unevenly over the sources with ~5 sources having the preponderance of the observations. The NAVEX schedules used a larger set of sources with more even distribution. While the same radio source catalog was used each day, the exact sequence of sources and the distribution of observing elevations and azimuths were different.

Since one aspect of the SGP R&D program is the study of troposphere modeling as an undesirable, nongeodetic signal, very low elevation observations were scheduled at certain stations. However, because the current troposphere models are insufficiently accurate at the lowest elevations, not all the data were included in the analysis. With a 7 degree cutoff, 14975 SGP observations and 2283 NAVEX observations were analyzed during the July 27 - August 10 period along with 3187 IRIS-A and 1294 NAVNET observations.

3. DATA ANALYSIS

The EOP values included in the present work were taken from a much larger complete solution including 1098090 observations between August 1979 - August 1993. The adjusted global parameters included positions and velocities of 117 sites and positions of 224 sources. The arc parameters included pole position, UT1, UT1 rate, offsets in obliquity and longitude, and piecewise-linear, continuous clocks and atmospheres. The geophysical, astronomical, and theoretical VLBI models generally followed the IERS standards. In addition, a model for the

TABLE 1. Stations and type for each session

			ADDFG	HHHKK	LMMMN	ORSSW	WHKT
			LSSDI	AAOAA	AAEOR	NIAEE	EOAR
			GSS-L	RYBSU	-TDJA	SCNSS	TFRO
			O14VC	TSAHA	VEIAO	AHTHT	TNLM
			P55LR	RTRII	LRCV8	LMIAF	Z BS
			A BE	AATM	BAIE5	AOANO	E UO
			R AE	OC2A	A N1	6N12R	L RN
			K K	K6	A23	0D25D	L GO
1	$92JUN22XI	IRIS-A	*----	-----	---*-	-*--*	*---
2	$92JUN23XH	IRIS-South	-----	*----	---*-	-*--*	*---
3	$92JUN23XO	USNO NAVEX	*---*	----*	-*--*	-----	----
4	$92JUN25XO	USNO NAVNET	----*	----*	----*	-*---	----
5	$92JUN29X	SGP Polar	-*--*	-*-*-	--*--	*----	----
6	$92JUN29XI	IRIS-A	*----	-----	---*-	-*--*	*---
7	$92JUN30X	SGP Research	---**	----*	*----	----*	*---
8	$92JUL02XO	USNO NAVNET	----*	----*	----*	-*---	----
9	$92JUL06XI	IRIS-A	-----	-----	---*-	*---*	*-*-
10	$92JUL07XQ	SGP Quake	---**	----*	---*-	-----	----
11	$92JUL08XH	IRIS-South	-----	*----	-----	-**-*	*---
12	$92JUL08XO	USNO NAVEX	*---*	----*	-*--*	-----	----
13	$92JUL09XO	USNO NAVNET	----*	----*	----*	-*---	----
14	$92JUL13XI	IRIS-A	----*	-----	---*-	-*--*	*---
15	$92JUL15X	SGP Pacific	--*-*	---**	-----	--**-	----
16	$92JUL16XO	USNO NAVNET	----*	----*	----*	-*---	----
17	$92JUL17XP	IRIS-Pacific	----*	--***	-----	-----	----
18	$92JUL20XI	IRIS-A	----*	-----	-----	*---*	**--
19	$92JUL20XS	NGS S. Survy	-----	*-*--	-----	--*--	----
20	$92JUL21X	SGP Global	----*	*-***	-----	--***	*---
21	$92JUL22X	SGP Global	----*	*-***	-----	--***	*---
22	$92JUL23XO	USNO NAVNET	----*	----*	----*	-*---	----
23	$92JUL25X*	Europe Mobil	----*	-----	-----	*---*	*---
24	$92JUL26X*	Europe Mobil	----*	-----	-----	*---*	**--
25	$92JUL27XI	IRIS-A	----*	-----	-----	*---*	**--
26	$92JUL28X	SGP Research	---**	----*	*----	----*	*---
27	$92JUL28XO	USNO NAVEX	-----	*--*-	-*--*	--*--	----
28	$92JUL29X	SGP Research	---**	----*	*----	----*	*---
29	$92JUL29XO	USNO NAVEX	*----	*--*-	-*--*	--*--	----
30	$92JUL30XO	USNO NAVNET	----*	----*	---*-	-*---	----
31	$92JUL31X	SGP Research	---**	----*	*----	----*	*---
32	$92AUG02X	SGP Research	----*	----*	*----	----*	*---
33	$92AUG03XI	IRIS-A	*----	-----	---*-	-*--*	*---
34	$92AUG04X	SGP Research	---**	----*	*----	----*	*---
35	$92AUG04XO	USNO NAVEX	-----	*--*-	-*--*	--*--	----
36	$92AUG05X	SGP Research	---**	----*	*----	----*	*---
37	$92AUG05XO	USNO NAVEX	*----	*--*-	-*--*	--*--	----
38	$92AUG06XO	USNO NAVNET	----*	----*	---**	-*---	----
39	$92AUG07X	SGP Research	---**	----*	*----	----*	*---
40	$92AUG09X	SGP Research	---**	----*	*----	----*	*---
41	$92AUG10XI	IRIS-A	*----	-----	---*-	-*--*	*---
42	$92AUG10XO	USNO NAVEX	----*	---**	-*--*	-----	----
43	$92AUG10XS	NGS S. Survy	-----	*-*--	-----	--*--	----
44	$92AUG11X	SGP T. Asia	--*--	*-**-	-----	---*-	*---
45	$92AUG12X*	Europe Mobil	----*	-----	-----	*---*	*---
46	$92AUG13XO	USNO NAVNET	----*	----*	----*	-*---	----
47	$92AUG17XI	IRIS-A	----*	-----	-----	*---*	*---
48	$92AUG18XH	IRIS-South	-----	*----	-----	-**-*	*---
49	$92AUG20XO	USNO NAVNET	----*	----*	----*	-*---	----
50	$92AUG24XI	IRIS-A	----*	-----	---*-	----*	*---
51	$92AUG25X*	Europe Mobil	-----	-----	-----	*---*	*--*
52	$92AUG26X*	Europe Mobil	----*	-----	-----	*---*	*--*
53	$92AUG27XO	USNO NAVNET	----*	----*	----*	-----	----
54	$92AUG28X*	Europe Mobil	----*	-----	-----	*---*	*--*
55	$92AUG29X*	Europe Mobil	----*	-----	-----	*---*	*--*
56	$92AUG31XI	IRIS-A	----*	-----	---*-	----*	*---
57	$92SEP01X	SGP Research	---*-	----*	*----	----*	*---
58	$92SEP03XO	USNO NAVNET	----*	----*	----*	-----	----
59	$92SEP07XI	IRIS-A	----*	-----	-----	*---*	*---
60	$92SEP10XO	USNO NAVNET	----*	----*	----*	-----	----
61	$92SEP14XI	IRIS-A	----*	-----	-----	----*	*---
62	$92SEP15XP	IRIS-Pacific	----*	--**-	-----	-----	----
63	$92SEP16XS	NGS S. Survy	-----	*-*--	-----	--*--	----
64	$92SEP17XO	USNO NAVNET	*---*	-----	----*	-----	*---
65	$92SEP21XI	IRIS-A	*---*	-----	-----	----*	*---
66	$92SEP22XO	USNO NAVEX	----*	---*-	-*--*	-----	----

diurnal and semidiurnal effects of ocean tides on UT1 and pole position was applied. The coefficients of this model (Gipson et al., 1993) were estimated directly from VLBI data in an earlier solution using the tidal frequencies and are given in Table 2. The effect of atmospheric pressure loading was calibrated using local pressures and coefficients derived from VLBI data and from global weather models (MacMillan and Gipson, 1994).

TABLE 2. Diurnal and semidiurnal EOP coefficients

Ten components for UT1

Tidal vector						cos (microseconds)	sin (microseconds)	Tidal Component
0	0	0	0	0	-1	7.486602	16.707637	K1
0	0	2	-2	2	-1	-3.500205	-5.392255	P1
0	0	2	0	2	-1	-15.575852	-16.762598	O1
1	0	2	0	2	-1	-3.394904	-3.902930	Q1
0	1	0	0	0	-1	.593333	1.932245	S1
1	0	0	0	0	-1	1.003345	1.299982	M1
0	0	0	0	0	-2	.261715	3.896805	K2
0	0	2	-2	2	-2	-1.182862	8.706599	S2
0	0	2	0	2	-2	-8.517385	12.338927	M2
1	0	2	0	2	-2	-4.378455	1.168543	N2

Twelve components for X and Y pole

Tidal vector						cos (microarcseconds)	sin (microarcseconds)	
0	0	0	0	0	1	125.285183	-38.476327	K1 p
0	0	-2	2	-2	1	-54.470359	26.152833	P1 p
0	0	-2	0	-2	1	-136.319298	63.668538	O1 p
-1	0	-2	0	-2	1	-33.990240	18.096315	Q1 p
0	0	0	0	0	-2	-15.899321	15.676795	K2 r
0	0	2	-2	2	-2	-76.296961	105.813157	S2 r
0	0	2	0	2	-2	15.018756	285.140733	M2 r
1	0	2	0	2	-2	-24.572257	58.610024	N2 r
0	0	0	0	0	2	22.589310	-5.801947	K2 p
0	0	-2	2	-2	2	-7.259654	-11.309321	S2 p
0	0	-2	0	-2	2	30.337902	-72.186765	M2 p
-1	0	-2	0	-2	2	-11.643736	-30.168262	N2 p

The orientation of the terrestrial reference frame (TRF) is essentially arbitrary and is derived from the EOP values adopted for the reference day, Feb. 12, 1993, and from the celestial angles of the standard precession/nutation models for the same reference day. The right ascension origin of the celestial reference frame is defined by the value assigned to the radio source 0420-012. The origin of the TRF is set by minimizing the adjustment of nine widely distributed, well observed stations with respect to their a priori values, which are within a few cm of ITRF92. The remaining degeneracies are removed by requiring no net rotation or vertical translation of eight stations (WESTFORD, GILCREEK, ONSALA60 (Sweden), WETTZELL, KAUAI, DSS45 (Australia) and HOBART26 (Tasmania)) with respect to the NUVEL-1 NNR plate model (Argus and Gordon, 1991). These stations are chosen to be minimally affected by plate boundary deformations, local movements, and as yet unexplained anomalies. It should be noted that any differences between the real relative motion of the reference stations and that predicted by the NUVEL-1 NNR model will cause all the stations to have fictitious apparent motions in the TRF.

The entire set of one-day EOP values and UT1 rates was estimated iteratively to improve the short-term accuracy, which affects the fit of each session. For each VLBI session, an offset from the a priori model was estimated for each component of polar motion. In addition, an offset and a rate were estimated for UT1. The total EOP at the middle of each session and the UT1 rate served as input to a simple Kalman filter, which estimated the EOP values at daily intervals. This new one-day-interval series served as the new a priori model for EOP. The a priori EOP values between tabular points at each observation epoch were obtained by linear interpolation. The one-day nutation offsets from the last iteration were spline fit to obtain daily nutation estimates for use in estimating the subdiurnal EOP values.

The solution to estimate subdiurnal EOP parameters modeled X-pole, Y-pole and UT1 as piecewise-linear, continuous functions with very weak constraints (1000 mas for pole, 100 ms for UT1) to bridge data gaps. The length of each linear segment was one hour. The global parameters and non-nutation arc parameters were the same as the solution for one-day EOP. The one-day-interval nutation series described above was used to remove the nutation errors that would have aliased into diurnal polar motion. Because of the weakness of the constraints, the hourly EOP values are noisy. However, the diurnal and semidiurnal harmonic signals are not significantly attenuated. A harmonic analysis of the hourly values from the complete solution gives components that are consistent with the direct estimate of the coefficients. With a stronger constraint to reduce the (visual) noise level, the simultaneous determination of hourly EOP from different networks shows generally good agreement. See Figure 1.

4. EOP RESULTS

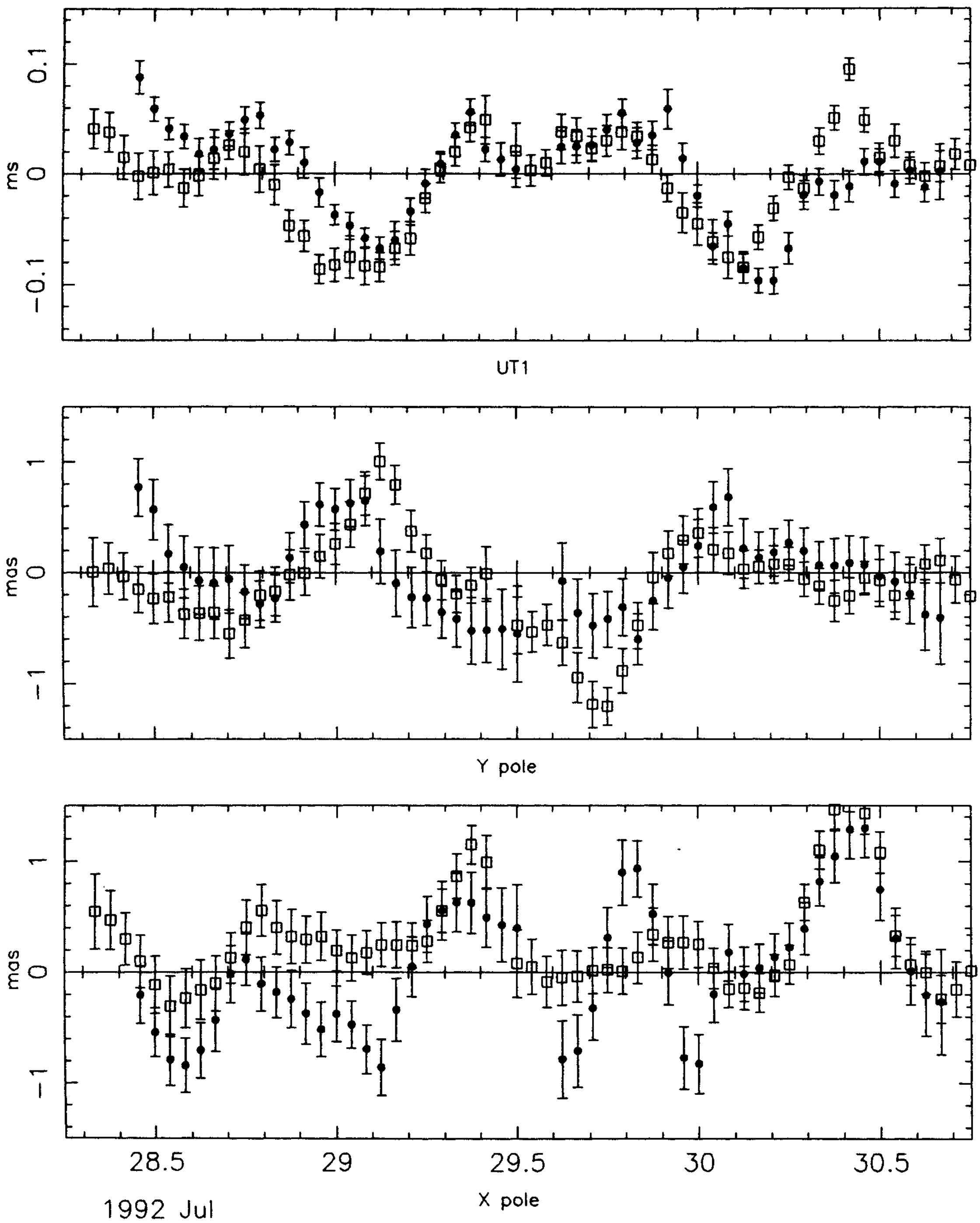
The EOP results are presented in two forms. The one-day estimates are submitted in the standard IERS format as EOP (GSFC) 93 R 06. It should be noted that the values include the diurnal and semidiurnal tidal effects evaluated at the stated epoch as well as terms with longer periods. No smoothing or model removal has been done. The hourly values are submitted in a straightforward format for each session as EOP (GSFC) 93 R 07. Some epochs appear more than once because observing sessions using different networks overlapped in time. Only the formal uncertainties are given.

The formal uncertainties of the results during SEARCH'92 are quite good. The best 1σ one-day errors are 90 μas in pole and 4 μsec in UT1. The best one-hour errors are 140 μas in pole and 8 μs in UT1. The median errors are somewhat worse for the one-day values, 190 μas in pole and 7 μs in UT1, but the median hourly errors are considerably worse, 650 μas for pole and 29 μs for UT1. The hourly EOP results are more affected by data dropouts.

5. OTHER ACTIVITIES

Because of the success of continuous VLBI EOP measurements during SEARCH'92, the Goddard VLBI group in cooperation with USNO and the VLBA (VLBI Array) undertook a similar continuous observing period called CONT94 between January 10-28, 1994. Up to three networks observed simultaneously. The SGP network included KOKEE (Hawaii), GILCREEK, LA-VLBA, FD-VLBA, WESTFORD, WETTZELL, and ONSALA60 and observed for 12 days

Figure 1. R&D (dot) and Navex-G (square) Measurements of EOP



between the routine weekly NEOS-A sessions. With 98% data yield, 42000 observations are expected. The remaining VLBA stations were used as an independent network. Because of extreme weather conditions and some station problems (particularly at Hancock and Kitt Peak), the data only covered 10 days with 40000 observations expected. The USNO NAVEX network observed on nine days with varying networks including NRAO85 3, ALGOPARK (Canada), FORTLEZA (Brazil), MATERA, HARTRAO, KASHIMA, MIZNAO10 (Japan), HOBART26, and KAUAI. The best EOP results should be a factor of two better than the results from SEARCH'92. The raw data will be correlated at the Mark IIIA correlators at the Haystack Observatory and USNO. This set of data will provide a complementary set to SEARCH'92 during the winter when the wet troposphere should be nearly negligible. The data and results should be available to investigators before the end of 1994.

6. REFERENCES

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