THE JPL/DSN J2000 RADIO REFERENCE FRAME

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Development of a radio reference frame of very high accuracy has become necessary in order to obtain the required accuracy in spacecraft navigation for current and future planetary missions. The antennas of the NASA Deep Space Network are being utilized on a regular basis to obtain the positions of over 100 compact extragalactic radio sources distributed over the sky down to a declination of -45 degrees with uncertainties of less than 0.005 arcseconds.

Very Long Baseline Interferometry (VLBI) observations on the intercontinental baselines formed by the DSN antennas in California, Spain and Australia have been taken since 1971. Only since 1978, however, has it been possible to make dual frequency (2.3 and 8.4 GHz) measurements which are necesary to remove the effects of charged particles in the transmission media. We report here results based on data taken from 1978 September to 1983 May, describe the differences from other radio astrometric programs, and give a comparison with other VLBI results.

A set of observations consists of 12 to 24 hours of data on each of the California-Spain and California-Australia baselines within an interval of 48 to 96 hours. Because of the lack of common visibility among all three sites, the observations cannot be simultaneous on both baselines. In a typical 23 hour period on one baseline approximately 230 observations are made of about 80 sources. The total number of sources that has been observed is ~130.

All data are recorded with the Mk II VLBI system and correlated on the JPL/CIT processor located at Caltech. The source positions are reduced in the J2000.0 system using precession, nutation, and Greenwich Sidereal Time as adopted by the IAU and prescribed in USNO Circular No. 163. The complete model for analysis of the data is described by Fanselow (1983) and includes relativistic transformations and gravitational bending of radio waves. The positions and velocities of the Earth, Moon, and nine planets are obtained using the JPL ephemeris

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DE200, which is consistent with the J2000.0 system. Since there is no means of determining the origin of right ascension from our VLBI observations, we have followed what has become customary practice and adopted the right ascension of 3C273 from the lunar occultations of Hazard et al (1971), transformed to J2000.0 (Kaplan, private communication).

A total of 3095 delay and 3080 delay rate observables has been acquired over the four and a half years of observations. These are used in a linear least-squares estimation of 652 parameters consisting of the positions of 132 sources (except the right ascension of 3C273), baselines for each observation set, the troposphere over each station for each set, and instrumental parameters, commonly called clock parameters. The resulting catalogue is designated JPL1983-4.

From these data we have obtained, for 120 of the sources, positions with uncertainties between 0.0006 and 0.0100 arcseconds. The sources are distributed in declination between -45 and +84 degrees with a slight concentration near the ecliptic, since that is the region for which reference sources for navigation are most needed (Figure 1). For 100 of these sources the uncertainties (one standard deviation) in both right ascension and declination are smaller than 5 mas (1 mas = 1 milli-arcsecond = 0.001 arcsecond). In order to assess the credibility of these uncertainties we have compared our results with the only other measurements of comparable accuracy, those of the GSFC/SAO/Haystack group (Ma et al, 1981). For the 50 sources in common we obtain the following comparison, in the sense GSFC - JPL1983-4:

	RA	DEC
Weighted mean difference:	0.0001 sec	-1.3 mas
Weighted RMS deviation:	1.5 mas	1.5 mas
Reduced chi-square:	1.3	2.6

Thus, although the chi-square calculation is for two standard deviations on the GSFC positions, it appears that the uncertainties are reasonable. Of the four possible comparisons (RA and DEC as a function of RA or of DEC) two are shown in Figure 2.

The current limiting error sources, each of which is thought to have a size of a few milliarcseconds, are a) the troposphere (calibration/ estimation/ mapping), b) Earth orientation parameters for precession and nutation, c) the frequency standards and/or frequency distribution systems, and d) instrumental delay calibration. Each of these error sources is being studied through the regularly scheduled observations and through separate engineering tests. For example, in order to evaluate the magnitude of any elevation-angle dependent errors, which might arise from incorrect troposphere mapping functions or from elevation dependent instrumentation problems, all observations made at elevation angles of less than 10 degrees were excluded and the solution was rerun. The result was a systematic change of approximately 3 mas in the declinations of all sources. If this change were applied as a correction to all declinations, the declination difference GSFC-JPL above would become slightly positive, perhaps indicating that the current declinations are biased slightly negative, although within the uncertainties.

The principles of VLBI astrometry are discussed in other contributions in this volume (Johnston 1986; Robertson 1986; Ma 1986). The significance of the excellent agreement between results of the two VLBI groups lies in the complete independence of implementation of the techniques, both in hardware and in software, including algorithms. In terms of hardware differences, we use the antennas of the NASA Deep Space Network. We record data on the Mark II VLBI system, using a time-sequential Bandwidth Synthesis technique, and do the cross-correlation on the JPL/Caltech correlator. The analysis is done on a VAX-based system using algorithms developed at JPL (Fanselow 1983). Differences extend to the troposphere models and planetary ephemerides which are used.

The long baselines obtained by using the DSN antennas provide high inherent accuracy. The large component along the earth's spin axis for the California/Australia baseline is especially advantageous since it provides very good accuracy in declination for sources near and below the equator. In addition we are able to observe sources down to -45 degrees, giving much better coverage of the celestial sphere. This is important to the navigation effort since the next two major spacecraft planetary encounters are near the intersection of the ecliptic and the Galactic Plane below -20 degrees declination. The disadvantage of such long baselines is that, since one antenna is in the southern hemisphere, observations cannot be made simultaneously at all three antennas for very many sources. Thus it is not possible to solve for all components of UT1-UTC and polar motion without some assumption or a priori information on the rates between the almost adjacent runs on the two baselines.

Finally, VLBI systems determine absolute declinations for the equator of date, but there is no determination of the origin of right ascension. In an associated program at JPL we are attempting to relate the frame of the extragalactic radio sources to that of the planetary ephemerides by several means: a) Direct ties have been obtained by differential VLBI measurements of the positions of radio sources relative to spacecraft orbiting the planets Mars and Venus (Newhall et al, 1986). The resulting uncertainty is a few hundredths arc second, and there is no significant offset when evaluated at epoch J2000.0. b) The position of Jupiter in the radio frame can be obtained by finding the positions of the Galilean satellites. This is being done using the VLA at 5 and 15 GHz. An uncertainty of 0.05 arc seconds is expected. c) An indirect determination of the offset in right ascension between the two frames may be found by comparison of the baselines between the observing antennas as determined by each type of measurement, that is, by VLBI for the radio sources and by the doppler and range measurements during spacecraft encounters with the planets. Again, the expected uncertainty is a few hundredths arc second.

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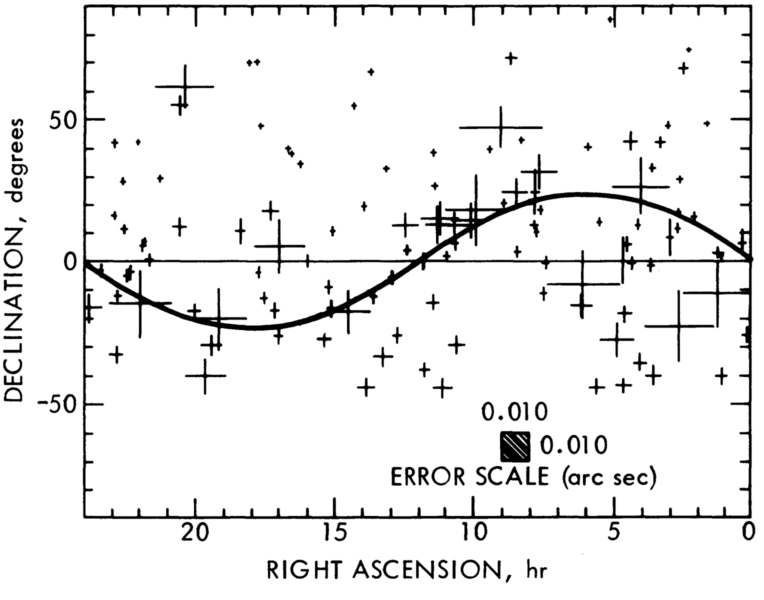

Figure 1. Schematic distribution of radio source positions and their uncertainties. Note the scale change for the error bars.

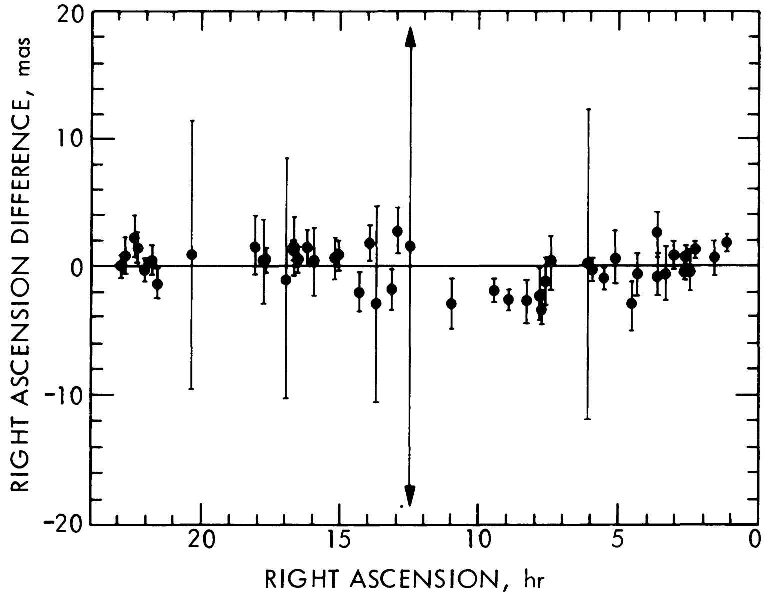

Figure 2a. Right ascension difference GSFC minus JPL1983-4 as a function of right ascension.

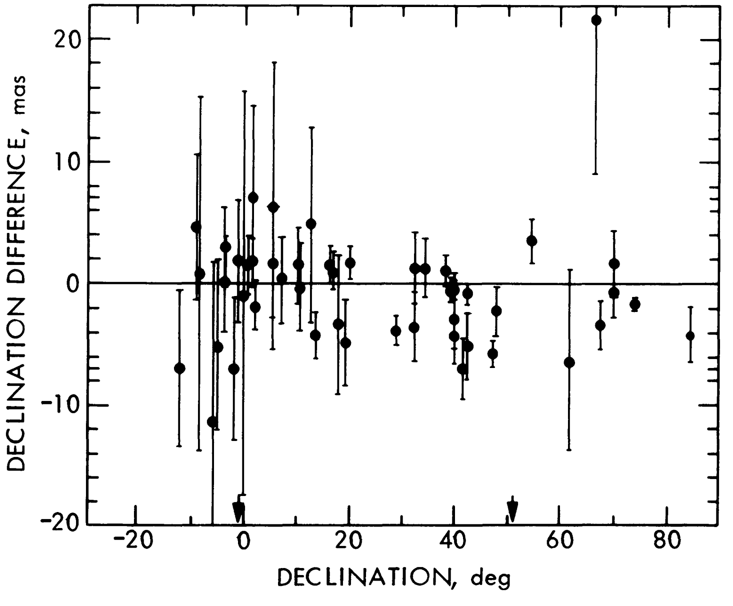

Figure 2b. Declination difference GSFC minus JPL1983-4 as a function of declination.

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