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B. GLOBAL REFERENCE FRAME: INTERCOMPARISON OF RESULTS (SLR, VLBI, GPS)

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The terrestrial reference frame (TRF) is realized by a set of positions and velocities derived from a combination of the three space geodetic techniques, SLR, VLBI and GPS. The standard International Terrestrial Reference Frame (ITRF) is constructed by the International Earth Rotation Service (IERS) in such a way that it is stable with time and the addition of new data. An adopted model for overall plate motion, NUVEL-1 NNR, defines the conceptual reference frame in which all the plates are moving. In addition to the measurements made between reference points within the space geodetic instruments, it is essential to have accurate, documented eccentricity measurements from the instrument reference points to ground monuments. Proper local surveys between the set of ground monuments at a site are also critical for the use of the space geodetic results. Eccentricities and local surveys are, in fact, the most common and vexing sources of error in the use of the TRF for such activities as collocation and intercomparison.

The global SLR and VLBI TRFs each consist of more than 100 sites occupied since the 1970s. Each technique is currently active at over 30 sites distributed globally although much more limited in the southern hemisphere. SLR stations operate independently and can potentially observe continuously, but weather and budget both limit actual observing in an unpredictable way. VLBI sessions must necessarily involve a network of stations observing simultaneously. VLBI observations are scheduled on a weekly basis on the NEOS (National Earth Orientation Service) network of five stations to monitor EOP (Earth Orientation Parameters).

With other geodetic observing programs coordinated by NASA, USNO, NOAA, IfAG, and GSI, there was on average during 1993 one 24-hour session every other day as well as a 1-hour session every non-NEOS day to monitor UT1. The fact that many SLR and VLBI sites are no longer active means, however, that the current realization of the TRF at these sites is gradually degraded as the mean epoch of observation recedes into the past and the current position is derived using velocities with finite or even unknown errors. The GPS TRF consists of over 40 IGS (International GPS Service) sites, some beginning as early as 1991, with permanent, continuously operating receivers. Like SLR and VLBI, the number of southern hemisphere sites is limited. The GPS data are retrieved remotely daily and the analysis products, orbits and EOP, derived by several analysis centers are distributed promptly to various data centers via Internet.

Table 1 shows, in round numbers, the contribution of each technique to the most recent ITRF realization, ITRF92. The WRMS is the scatter of the results from a particular technique from

ITRF92, which incorporated all the techniques using results from several analysis centers for each technique. No GPS velocities were included because of the limited GPS time interval when the results entering ITRF92 were generated in early 1993. It can be seen that the scatters are similar. The CSR-University of Texas SLR results were used to set the scale and origin of ITRF92.

TABLE 1

Contributions to ITRF92 from SLR, VLBI and GPS

WRMS scatter

	Sites	Position (mm) horiz	Position (mm) vert	Velocity (mm/yr) horiz	Velocity (mm/yr) vert
SLR	110	15	20		
	45			1.5	3.0
VLBI	110	5	10		
	60			0.6	1.0
GPS	45	10	15		

The different Celestial Reference Frames (CRF) used by the different techniques have a direct bearing on the complexity of analysis and the stability and accuracy of the TRF parameters that can be estimated. VLBI uses 130 extragalactic radio sources that constitute a nearly inertial CRF. The technique is geometric with no ties to the geocenter but can measure the complete orientation of the Earth accurately over the long term. SLR uses the orbits of 5 satellites specifically designed for geodetic ranging. While the orbits can be integrated for up to a few weeks, there exist unmodelable drifts in the orbit node that preclude the long-term measure of UT1. However, the determination of the geocenter is strong. GPS uses the orbits of 25 complicated, actively maneuvered, distant satellites, so that both the orbit stability and the tie to the geocenter are weak. However, the quantity of data acquired from continuous observing as well as considerable mutual visibility of the satellites from different sites provide strong daily solutions for station and pole positions.

Tables 2 and 3 from Watkins, Eanes and Ma (GRL in press) shows the most recent comparison between SLR and VLBI for position at 1988.0 and velocity. While the number of sites with both position and velocity estimated from both techniques is limited, they are globally distributed. The common sites are, unfortunately, among the weaker sites for both techniques. The agreement is better than 10 mm WRMS for the horizontal components and 20 mm in the vertical. The WRMS agreement in horizontal velocity is ~2 mm/yr.

Table 2
Position Comparison - GLB886a/CSR93L01

Sites	Differences After Fit (mm)						Uncertainties (mm)		
	X	Y	Z	East	North	Vert.	σ_E	σ_N	σ_V
Tidbinbilla	-34	2	-29	16	-6	42	14	21	19
Greenbelt	6	-29	9	12	10	-27	6	4	9
Ft. Davis (N)	3	-21	8	8	-3	21	7	8	11
Ft. Davis (O)	-2	12	11	-5	15	-4	8	10	14
Mon. Peak	6	3	-7	4	-3	-8	5	4	8
Plattevile	-2	-1	-2	-2	-2	0	8	7	17
Quincy	-4	-1	3	-3	-3	1	4	4	8
Shanghai	-20	87	95	-28	37	122	41	36	56
Wettzell	18	-17	25	-19	6	28	9	11	16
Matera	-13	-20	6	-15	16	-10	12	14	20
Weighted rms	9	15	10	9	7	19			

Table 3
Velocity Comparison - GLB886a/CSR93L01

Sites	Differences After Fit (mm)					Uncertainties (mm)	
	X	Y	Z	East	North	σ_{VE}	σ_{VN}
Tidbinbilla	5.2	-8.7	-2.9	4.8	-7.3	2.2	2.4
Greenbelt	-2.2	-1.4	-2.3	-2.4	-2.3	1.4	1.1
Ft. Davis (N)	-1.8	-1.9	3.1	-1.3	1.5	1.6	1.6
Ft. Davis (O)	-2.0	-2.4	2.1	-1.3	0.3	2.4	2.2
Mon. Peak	1.3	0.6	1.7	0.9	2.0	1.0	1.0
Plattevile	0.4	1.4	1.2	0.0	1.9	2.1	2.0
Quincy	0.5	-0.4	-0.2	0.6	-0.2	1.0	1.1
Shanghai	-7.7	-8.7	-5.8	11.1	6.7	11.4	9.9
Wettzell	0.3	-1.0	2.9	-1.0	1.8	2.2	2.3
Matera	-0.6	-3.6	5.0	-3.3	4.8	2.5	2.6
Weighted rms	4.5	4.3	2.8	1.8	2.5		

Tables 4 and 5 show the comparison between GPS and VLBI at 1992.5. The GPS sites have data spanning up to three years. It can be seen that the position comparison is slightly worse than SLR-VLBI while the velocity comparison is considerably worse. There are some sites that have such large discrepancies in velocity that they are excluded from the comparison. Generally these are in the southern hemisphere, where coverage is weak.

The unique contributions of each technique are summarized as follows:

Contributions to the TRF

SLR:

- center of mass
- longest pole and LOD series
- scale

VLBI:

- tie to inertial frame
- stable pole, UT1, nutation series
- precision/accuracy
- site velocities

GPS:

- daily measurements of position
- pole densification

Table 4

GPS-VLBI Position Differences After Transformation - mm

	Up	East	North	Magnitude
ALGOPARK	-37	-7	0	38
DSS45	-54	24	6	60
DSS65	34	10	-16	39
GILCREEK	-5	-8	1	10
HARTRAO	5	-6	22	24
JPL MV1	-44	-12	8	46
KAUAI	24	-2	-3	24
MATERA	4	11	-5	13
METSHOVI	-28	0	-27	39
MOJAVE12	-7	0	-14	15
NL-VLBA	-20	-3	-4	21
ONSALA60	3	7	-14	16
PENTICTN	-67	-5	-2	68
PIETOWN	3	-1	-9	10
PINFLATS	3	-6	-4	8
RICHMOND	-26	-9	11	30
SANTIA12	55	12	8	58
TROMSONO	2	-42	3	42
VNDNBERG	0	-10	-6	12
WETTZELL	3	1	-4	5
YELLOWKN	50	0	0	50
Weighted RMS	31	13	11	

Table 5

GPS-VLBI Rate Differences After Rotation - mm/yr
(x-not included in rotation or statistics)

		Up	East	North
	ALGOPARK	-2.9	4.1	-2.1
	DSS45	-2.3	-14.8	-2.2
	DSS65	7.3	5.2	-1.4
	GILCREEK	9.6	6.4	-4.2
X	HARTRAO	4.0	29.1	1.7
X	HOBART26	1.5	-22.4	-3.9
X	JPL MV1	-22.5	-3.8	6.2
	KAUAI	0.4	5.8	0.4
	MATERA	-9.5	6.5	-0.3
	METSHOVI	-6.8	-1.3	1.1
	MOJAVE12	-0.9	-4.9	-3.1
	NL-VLBA	5.5	1.8	7.4
	ONSALA60	0.0	4.1	1.2
X	PENTICTN	-26.9	0.6	-1.7
	PIETOWN	-0.8	-1.3	9.2
	PINFLATS	-5.5	-1.1	2.0
	RICHMOND	10.8	2.8	-0.9
X	SANTIA12	-59.2	23.5	-23.3
	TROMSONO	-4.0	-13.9	1.3
	VNDNBERG	5.6	-8.3	1.8
	WETTZELL	-7.8	5.3	-4.0
	YELLOWKN	-3.0	1.7	-4.3
	RMS	5.9	6.5	3.6