OPTICAL OBSERVATIONS OF TIME AND LATITUDE AND THE DETERMINING OF THE EARTH'S ROTATION PARAMETERS IN 1980

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I. GENERAL SITUATION

This paper is based on optical observations of 85 instruments (Table 1-a) from January to October 1980. The accuracies of all instruments, 62 for time and 54 for latitude, are shown in Table 1-b, in which :

- the roughness ε_{1i} of daily observations is defined by the standard deviation of the observation values of the i-th instrument with respect to the smoothed values of themselves;
- the ε_{2i} is the standard deviation of mean observation values during every 0.05 year with respect to the global reference system.

The average accuracy of each type of instrument is given in Table 2, regional averages are given in Table 3.

These tables show that errors in time observations are greater, generally speaking, than those in latitude, and low frequency errors are greater than high frequency ones in time observations.

II. THE NORMAL SOLUTION OF THE EARTH'S ROTATION PARAMETERS

This solution is similar to the BIH method and based upon as much data as possible, and is used to give the values of the Earth rotation parameters. The briefing is as follows :

1/ Every group of time or latitude observations is corrected for the vertical deflection and the Earth tides due to the Moon, and the diurnal nutation.

2/ The error equations are :

$$(\phi - \phi_0)_i = x' \cos\lambda_i + y' \sin\lambda_i + z \qquad (1)$$
$$(UT_0 - UT_c)_i = (UT_1 - UT_c) + (-x \sin\lambda_i + y \cos\lambda_i) \operatorname{tg}\phi_i$$

3/ The observables $(\phi - \phi_0)_i$ and $(UT_0 - UT_c)_i$ in formula (1) are corrected for systematic errors which are computed using parameters

O. Calame (ed.), High-Precision Earth Rotation and Earth-Moon Dynamics, 11–23.

TABLE 1-a. Classical instruments participating to the short campaign.

N°	Code	Instr.	Observatory	Country
1	BAA	ASTR	Buenos-Aires	Argentina
2	BAN	IP	Buenos-Aires	Argentina
3	BG	IPP	Borova Gora	Poland
4	BJA	ASTR	Beijing	China
5	BJB	PASTR	Beijing	China
6	BJF	IPP	Beijing	China
7	BK	LZ	Blagovestchensk	USSR
8	BLI	IP	Belgrade	Yugoslavia
9	BLZ	LZ	Belgrade	Yugoslavia
10	BOJ	IP	Berowice	Poland
11	BOZ	LZ	Berowice	Poland
12	BR	IP	Bratislava	Czechoslovak
13	BU	IP	Bucarest	Romania
14	CA	LZ	Caloforte	Italy
15	CL	PZT	Calgary	Canada
16	D	LZ	Dresden	DDR
17	DDZ	LZ	Dehra Dun	India
18	EK	LZ	Kazan	USSR
19	G	PZT	Herstmonceux	England
20	GO	LZ	Gorki	USSR
21	GRB	ASTR	Grasse	France
22	GRC	ASTR	Grasse	France
23	GT	LZ	Gaithersburg	USA
24	H	PZT	Hamburg	FDR
25	IRB	ASTR	Irkoutsk	USSR
26	IRC	ASTR	Irkoutsk	USSR
27	IRF	IPP	Irkoutsk	USSR
28	IRZ	LZ	Irkoutsk	USSR
29	KB	LZ	Kitab	USSR
30	KHF	IPP	Kharkov	USSR
31	KTP	PZT	Kitab	USSR
32	KZ	LZ	Kitab	USSR
33	LA	IPP	Leningrad	USSR
34	LMI	IP	Leningrad	USSR
35	MA	IPP	Moscow	USSR
36	MAF	IPP	Moscow	USSR
37	MAP	PZT	Moscow	USSR
38	MIA	ASTR	Milan	Italy
39	MMF	IPP	Moscow	USSR
40	MS	PZT	Mount Stromlo	Australia
41	MZA	ASTR	Mizusawa	Japan
42	MZL	LZ	Mizusawa	Japan
43	MZQ	PZT	Mizusawa	Japan
44	MZZ	LZ	Mizusawa	Japan
45	NJF	IPP	Nanjing	China
46	NK	IPP	Nikolaiev	USSR
47	NMI	IP	Novossibirsk	USSR
48	OJP	PZT	Ondrejov	Czechoslovak

TABLE 1-a (continued)

N°	Code	Instr.	Observatory	Country
49	OS	PZT	Ottawa	Canada
50	PA	ASTR	Paris	France
51	PIP	PZT	Punta Indio	Argentina
52	POZ	LZ	Poltava	USSR
53	PTA	ASTR	Potsdam	DDR
54	PTP	PZT	Potsdam	DDR
55	PUG	IPP	Pulkovo	USSR
56	PUH	IPP	Pulkovo	USSR
57	PUZ	LZ	Pulkovo	USSR
58	PYD	CIRC	Pecny	Czechoslovakia
59	PYZ	LZ	Pecny	Czechoslovakia
60	RCP	PZT	Richmond	USA
61	RG	IPP	Riga	USSR
62	RJ	IPP	Rio de Janeiro	Brazil
63	RM	IP	Rome	Italy
64	SC	ASTR	Santiago	Chile
65	SDZ	LZ	Sodankyla	Finland
66	SFA	ASTR	San-Fernando	Spain
67	SJ	ASTR	San-Juan	Argentina
68	SOI	IP	Sofia	Bulgaria
69	SXA	PASTR	Shaanxi	China
70	SXF	IPP	Shaanxi	China
71	TAF	IPP	Tachkent	USSR
72	TAI	IP	Tachkent	USSR
73	TJZ	LZ	Tianjin	China
74	TO	PZT	Tokyo	Japan
75	TT	LZ	Turku-Tuorla	Finland
76	ULI	IP	Ulan Bator	Mongolia
77	ULZ	LZ	Ulan Bator	Mongolia
78	UK	LZ	Ukiah	USA
79	VJZ	LZ	Warsow	Poland
80	W	PZT	Washington	USA
81	WHA	ASTR	Wuchang	China
82	WHF	IPP	Wuchang	China
83	ZIA	ASTR	Shanghai	China
84	ZIB	PASTR	Shanghai	China
85	ZIF	IPP	Shanghai	China

ASTR : Danjon astrolabe
IP : Visual Transit Instrument
IPP : Photoelectric Transit
PZT : Photographic Zenith Tube
PASTR : Photoelectric Astrolabe
LZ : Zenith Telescope
CIRC : Circumzenithal

TABLE 1-b. Estimation of accuracy of every instrument.

N°	Code	ε_{u1}	Code	ε_{u2}	Code	$\varepsilon_{\phi 1}$	Code	$\varepsilon_{\phi 2}$
1	OS	36	ZIB	19	OS	38	OS	19
2	PIP	38	PIP	21	PIP	42	TO	22
3	SXF	41	OS	23	TT	45	CL	23
4	ZIB	42	CL	26	MIA	48	SXA	28
5	BAN	44	SXA	30	TJZ	51	TT	28
6	WHF	45	OJP	31	BJB	53	RCP	30
7	G	47	RCP	33	ZIB	55	W	32
8	ZIF	48	TO	34	CL	56	PIP	32
9	SC	49	SC	36	PA	57	ZIB	33
10	SXA	49	KHF	37	BLZ	58	BJB	34
11	BJB	53	BJA	39	TO	61	BK	35
12	ZIA	56	BJF	39	PTP	61	TJZ	36
13	TO	59	ZIF	41	PYZ	63	PUZ	36
14	MS	59	BJB	42	G	64	SFA	37
15	RCP	60	WHF	45	GRB	67	PA	38
16	CL	60	NJF	53	BK	68	SC	39
17	NJF	63	MA	53	RCP	68	IRZ	39
18	OJP	65	GRB	56	H	68	MS	41
19	WHA	66	MZA	56	SC	69	EK	46
20	MIA	67	MAP	62	SFA	69	G	47
21	BG	68	MAF	66	SDZ	70	GO	47
22	GRB	68	MZQ	74	OJP	70	MZQ	48
23	BJF	69	PUG	74	D	71	BLZ	49
24	MA	70	SFA	79	VJZ	73	MIA	53
25	H	71	WHA	80	MS	73	VJZ	53
26	RG	75	W	81	EK	76	BJA	56
27	NK	77	IRF	83	MZQ	77	SJ	58
28	BJA	79	G	86	SXA	77	H	59
29	MZQ	80	ZIA	87	IRZ	79	PTP	60
30	LA	80	MIA	101	BOZ	79	PYZ	64
31	NMI	80	SXF	109	W	82	SDZ	73
32	IRC	86	SJ	120	PYD	82	OJP	73
33	PA	86	MS	121	MZA	88	BOZ	75
34	PYD	86	BG	121	ULZ	88	MAP	78
35	SOI	89	BR	123	GRC	88	MZL	81
36	PTP	89	MMF	125	POZ	89	WHA	82
37	IRB	91	BLI	130	ZIA	91	D	82
38	GRC	92	BOJ	140	PUZ	92	PYD	83
39	BOJ	92	GRC	145	PTA	94	ZIA	87
40	TAF	92	PYD	147	GT	96	KB	88
41	SFA	92	PUH	150	WHA	98	GRB	91
42	MAF	93	LMI	153	MAP	100	GRC	95
43	RM	93	PTP	155	KB	100	KZ	97
44	MZA	93	BAA	171	MZZ	109	ULZ	101

TABLE 1-b (continued)

45	KHF	98	H	191	KZ	109	KTP	106
46	LMI	100	IRC	193	UK	109	MZA	108
47	KTP	100	RG	194	MZL	111	MZZ	109
48	BAA	101	SOI	203	BJA	115	GT	112
49	W	103	NMI	215	BAA	122	UK	124
50	IRF	105	TAF	222	SJ	129	PTA	137
51	PUG	109	PTA	230	CA	135	POZ	139
52	PTA	112	LA	231	KTP	172	DDZ	175
53	BR	112	IRB	238	DDZ	191	CA	181
54	MAP	114	TAI	238	GO	205	BAA	220
55	PUH	122	BAN	256				
56	RJ	126	KTP	266				
57	TAI	133	PA	269				
58	MMF	151	NK	287				
59	SJ	163	BU	300				
60	BLI	211	ULI	301				
61	BU	316	RM	449				
62	ULI	364	RJ	527				

Units :
$0\overset{s}{.}0001$ for ε_{u1} and ε_{u2}
$0\overset{''}{.}001$ for $\varepsilon_{\phi 1}$ and $\varepsilon_{\phi 2}$

TABLE 2. The average accuracy of type of instrument

		PASTR	PZT	ASTR	IPP	LZ	IP
UT	ε_1	48	70	87	83		147
($0\overset{s}{.}0001$)	ε_2	30	86	126	114		248
ϕ	ε_1	62	74	87		94	
($0\overset{''}{.}001$)	ε_2	32	48	85		83	

TABLE 3. Regional averages of accuracies

		China	America	USSR	Europe	Others
UT	ε_1	56	78	117	77	73
($0\overset{s}{.}0001$)	ε_2	53	129	169	172	71
ϕ	ε_1	77	81	93	77	101
($0\overset{''}{.}001$)	ε_2	51	69	75	73	83

TABLE 4-a. Raw values of the rotation parameters for every 5 days from optical observations.

MJD	UT_1-UT_c	Δlod	X	Y	MJD	UT_1-UT_c	Δlod	X	Y
44239	6476		68	296	44439	1792	165	-48	306
244	6355	260	134	288	444	1699	166	-21	288
249	6216	282	98	235	449	1626	156	-22	298
254	6073	294	110	247	454	1543	180	2	305
259	5922	282	105	215	459	1446	163	-26	310
264	5791	260	91	209	464	1380	166	-29	305
269	5662	228	97	204	469	1280	179	-10	296
274	5563	211	63	183	474	1201	176	-27	303
279	5451	206	58	176	479	1104	214	-19	316
284	5357	232	69	184	484	987	224	-26	321
289	5219	276	33	174	489	880	199	-15	306
294	5081	287	78	176	494	788	218	- 5	329
299	4932	272	69	154	499	662	237	-20	330
304	4809	240	62	168	504	551	238	-26	305
309	4692	225	55	162	509	424	257	1	333
314	4584	259	36	203	514	294	243	- 7	337
319	4433	233	20	164	519	181	238	- 9	342
324	4351	240	15	184	524	56	251	-10	375
329	4193	318	6	183	529	- 70	274	4	341
334	4033	288	-22	191	534	-218	277	-47	361
339	3905	242	-21	197	539	-347		-40	368
344	3791	250	-30	210					
349	3655	240	- 7	208					
354	3551	245	-38	220					
359	3410	274	-33	224					
364	3277	253	-53	219					
369	3157	269	-46	216					
374	3008	253	-55	223					
379	2904	185	-46	241					
384	2823	208	-54	262					
389	2696	228	-47	248					
394	2595	209	-60	256					
399	2487	212	-45	256					
404	2383	208	-68	251					
409	2279	190	-74	261					
414	2193	153	-69	274					
419	2126	154	-20	264					
424	2039	188	-74	282					
429	1938	175	-78	286					
434	1864	146	-45	270					

Units : $0\overset{\mathrm{s}}{.}0001$ for UT_1-UT_c
$0\overset{\mathrm{s}}{.}00001$ for Δlod
$0\overset{\prime\prime}{.}001$ for X and Y

TABLE 4-b. Smoothed values of Table 4-a

MJD	UT$_1$-UT$_c$	Δlod	X	Y
44239	6483		82	300
244	6349	280	104	275
249	6209	281	113	253
254	6068	281	112	235
259	5928	272	105	220
264	5796	253	95	208
269	5675	234	83	197
274	5562	223	71	189
279	5452	225	62	182
284	5337	240	58	177
289	5212	257	59	173
294	5080	266	63	169
299	4946	263	65	167
304	4817	253	62	168
309	4693	244	53	172
314	4573	243	40	176
319	4450	251	25	179
324	4322	262	11	182
329	4188	272	- 1	186
334	4050	272	-12	192
339	3916	263	-19	199
344	3787	255	-23	206
349	3661	251	-26	212
354	3536	253	-31	216
359	3408	258	-38	218
364	3278	258	-44	220
369	3150	251	-48	224
374	3027	237	-51	231
379	2913	223	-51	240
384	2804	216	-51	248
389	2697	213	-52	253
394	2591	211	-55	255
399	2486	207	-58	256
404	2384	198	-61	258
409	2288	185	-62	261
44439	1785	162	41	291
444	1074	163	29	295
449	1622	164	19	300
454	1540	165	15	303
459	1457	167	16	304
464	1373	171	18	304
469	1286	179	20	305
474	1194	189	22	307
479	1097	200	21	311
484	994	209	20	315
489	888	216	18	317
494	778	224	16	320
499	664	232	15	321
504	546	238	13	323
509	426	243	9	329
514	303	247	4	337
519	179	250	0	346
524	53	255	1	353
529	76	264	4	358
534	211	273	18	361
539	349		41	365

Units : $0\overset{s}{.}0001$ for UT$_1$-UT$_c$

$0\overset{s}{.}00001$ for Δlod

$0\overset{''}{.}001$ for X and Y

a, b,... presented by BIH.

4/ The rotation parameters for every 5 days are solved according to equation group (1) with weights :

$$p_{1i} = 1 / (\varepsilon_{1i}^2 + \varepsilon_{2i}^2)$$

where the mean of ε_{1i} and ε_{2i} is as stated above, while those for every 0.05 year are done with weights p_{2i} which are considered in referring to those in the last four years and the actual situation in 1980.

Raw values of parameters for every 5 days are given in Table 4-a and their smoothed values in Table 4-b. The averages in every 10 days of l.o.d. variation (Δlod) are given in these tables, too. The corresponding values for every 0.05 year are given in Table 5.

III. SOME TESTING SOLUTIONS OF THE ROTATION PARAMETERS

Besides the normal solution, some testing solutions have been conducted :

Testing solution I :

We selected 18 series of time and latitude, respectively, whose the accuracies are the highest among all 116 series. We got a set of parameters with the same method as that of the normal solution. The average internal accuracies and the roughnesses of raw values for every 5 days of these two solutions are given as follows :

TABLE 6.

	Internal accuracy			Roughness		
	UT_1 $\pm 0^{s}.0001$	X $\pm 0''.001$	Y $\pm 0''.001$	UT_1 $\pm 0^{s}.0001$	X $\pm 0''.001$	Y $\pm 0''.001$
Testing	13	19	16	10	13	10
Normal	12	16	15	10	12	9

These two solutions are very close in accuracy. This means that the other 80 series, which are not used for the testing one, make only a tiny contribution to determine the rotation parameters. The weights of the series for the testing one are high and the geographical distribution of these instruments is fairly so uniform that are no great differences between the weights of the unknowns of both testing and normal solutions (Table 6).

This is why the accuracy of the testing one is almost as high as that of the normal one although the number of observation series used for the former only amounts to 1/3 of that for the latter.

TABLE 5. Raw values of the rotation parameters for every 0.05 year from optical observations.

T	UT_1-UT_C $0^{s}0001$	Δlod $0^{s}00001$	X $0''001$	Y $0''001$	Z $0''001$
1980.05	5976	245	108	225	-44
.10	5529	243	68	186	-42
.15	5086	255	63	169	-48
.20	4620	256	45	174	-40
.25	4152	265	- 4	187	-13
.30	3572	256	-26	211	-19
.35	3205	233	-47	222	-21
.40	2780	210	-51	249	- 5
.45	2397	179	-61	258	-11
.50	2070	164	-61	274	1
.55	1771	164	-39	292	- 4
.60	1471	177	-15	304	0
.65	1148	211	-22	309	2
.70	763	238	-16	320	0
.75	329	254	- 5	336	- 7
.80	- 135		- 9	359	-22

TABLE 7. (same units)

		Internal accuracy			Roughness			Weight		
	N	UT_1	X	Y	UT_1	X	Y	UT_1	X	Y
Test 1	36	13	19	16	10	13	10	727	766	1081
Test 5	98	15	18	17	14	14	13	550	880	953
Normal	116	12	16	15	10	12	9	835	1056	1202

Testing solution II :

Let parameters for system correction b=c=...=e'=0, we got a set of rotation parameters with the same method as that of the normal one. Besides we also solved the rotation parameters in the 1968 BIH system using a, b, ... e' in 1968 system. This solution is called the normal solution (1968).

The differences ΔUT_1 and ΔX between the two sets of rotation parameters from the test solution and from the normal solution (1968) are illustrated in Figures 1a and 1b, and the system differences BIH(1979)-BIH(1968), i.e. :

$$\begin{aligned} C_t &= 0^{s}.0007 \sin 2\pi\,(t-0.447) + 0^{s}.0007 \sin 4\pi\,(t-0.397) \\ C_x &= 0''.024 \sin 2\pi\,(t-0.159) + 0''.007 \sin 4\pi\,(t-0.289) \end{aligned} \qquad (2)$$

are shown there, too. We can see that there are good agreements between ΔUT_1 and C_t, as well as ΔX and C_x. This testing is repeated with the data of 1976 and the same agreements as that of 1980 are shown. It seems that there are no obvious systematic differences between optical and new techniques. The C_x and C_t given by the BIH are only residual errors of BIH stations at the moment of establishing the BIH 1968 system, and have been kept up to now.

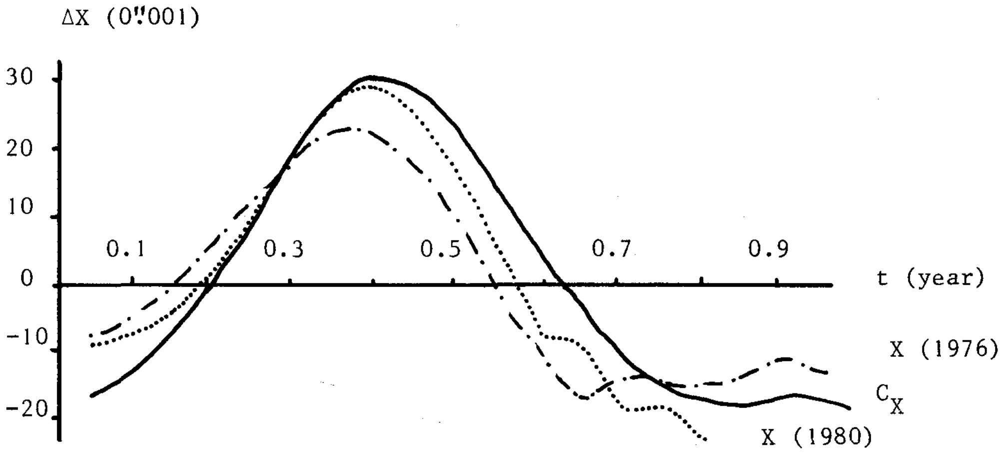

Fig. 1a. X-component of systematic difference

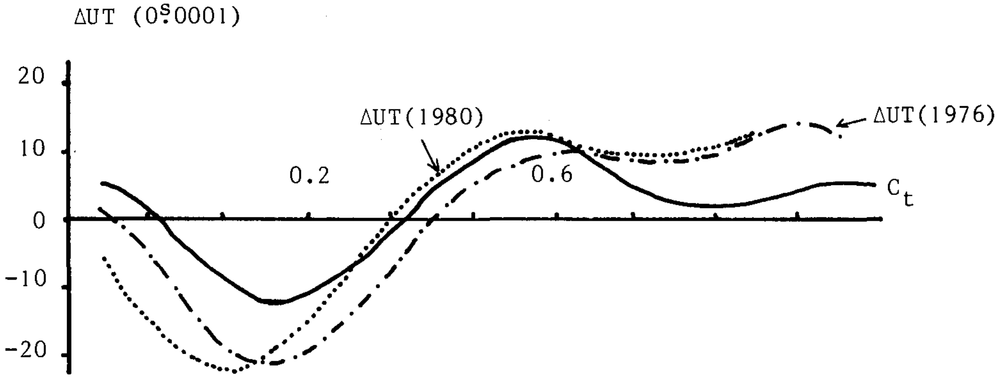

Fig. 1b. UT-component of systematic difference

Testing solution III :

After correcting every group of observations with the nutation coefficients deduced from Wahr's theory, we got a set of the rotation parameters with the same method as the normal one.

The corrections to observations are computed according to the formula :

$$\Delta UT_{0i} = \Delta\psi \cos\varepsilon + (\Delta\psi \sin\varepsilon \sin\alpha - \Delta\varepsilon \cos\alpha)\, \mathrm{tg}\phi_i$$
$$\Delta\phi_i = \Delta\psi \sin\varepsilon \cos\alpha + \Delta\varepsilon \sin\alpha$$

where $\Delta\psi$, $\Delta\varepsilon$ are the differences between two sets of nutation coefficients from Wahr and Woolard theories; α is the central right-ascension of observed star group.

The $\Delta\phi_i$ does not affect X and Y but only Z-term because of its independence to the geographical position of the station. As for UT_{0i}, the first term $\Delta\psi\cos\varepsilon$ is also independent to the position of the station so that it does not affect X and Y but only UT_1-UT_c; although the second term $(\Delta\psi\sin\varepsilon\sin\alpha-\Delta\varepsilon\cos\alpha)\mathrm{tg}\phi_i$ is dependent on the latitude of the station, it mainly affects UT_1-UT_c and hardly affects X and Y when the formula (1) is regarded as error equation, because most of the stations are concentrated in a narrow zone of latitude. Therefore, the effects of errors of nutation coefficients are mainly involved in Z-term and UT_1-UT_c. However, the latter is hardly distinguished from the variation of the rotation rate of the Earth. The hope of examining nutation coefficients only place on Z-term. It is a pity that effects of these two sets of coefficients to Z-term are almost equal in 1980. Thereby, the advantage of Wahr's nutation series is not fully reflected in classical data of 1980.

Testing solution IV :

In order to study regional effect, we divided the most of instruments into 3 groups, namely, Europe, America, East Asia; the weight assigned for each region was increased to 4 times more than the normal solution in turn. Several sets of rotation parameters are obtained with the same method as that of the normal one. Comparing them with the normal solution, we find that they likely contain some systematic differences as distinct from each other, and that change of rotation parameters obtained when the weight of East Asia was amplified, was almost opposite to those obtained when the weight of America was amplified. Thus, regional effect of unknown sources is suspected.

Moreover, we also compared the UT_1 values of the Chinese Joint System with the global normal solution. Significant difference was found (Fig. 3), although the internal agreement of the Chinese instruments was good.

Testing solution V :

Using global observations without Chinese data, we obtained a set of rotation parameters with the same method as the normal one.

Precisions of testing solutions I, V and the normal one are shown

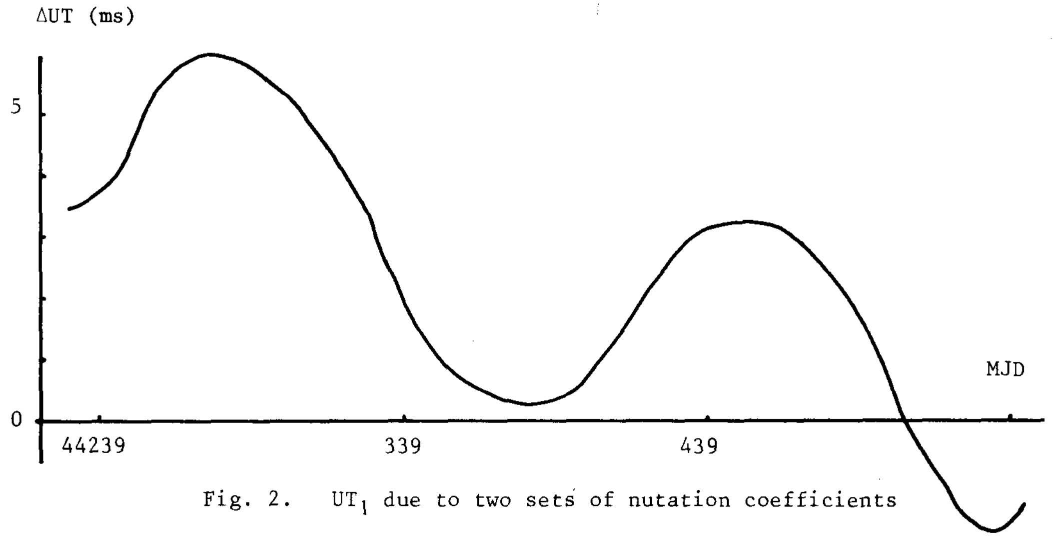

Fig. 2. UT_1 due to two sets of nutation coefficients

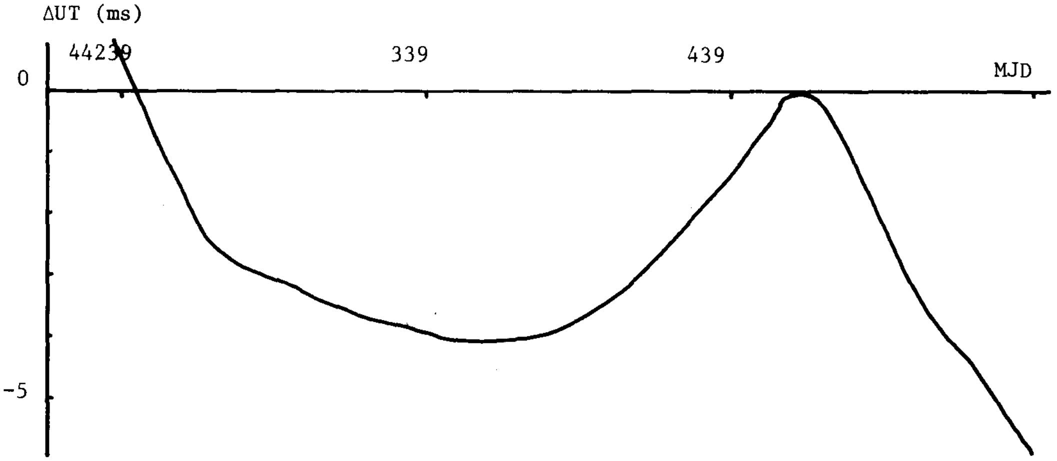

Fig. 3. UT_1 between the normal solution and the Chinese System

in Table 7, where N is the number of observation series used in each solution.

This comparison indicates that Chinese instruments will make important contribution to the establishment of a stable reference system. In 1980, the weight of UT_1, X and Y increased by 52%, 20% and 26%, respectively, when Chinese instruments joined in the global solution.

IV. CONCLUSIONS

1/ A better reference system, which is comparable to BIH in accuracy, may be formed using less instruments with high accuracy and reasonable distribution.

2/ There do not seem to be any obvious annual and semi-annual differences between the results of optical and new techniques. The differences BIH(1979)-BIH(1968) are likely due to some residual errors of BIH stations at the moment of establishing the BIH 1968 system and have been kept up to now.

3/ Some common error sources probably exist in a large region. Instruments should be distributed as uniformly as possible in order to establish a stable reference system.

4/ Chinese instruments will make an important contribution to establishing and maintaining the reference system.