THE OBSERVATIONS OF THE EARTH ROTATION AND THE STELLAR SYSTEM

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1. Introduction

The fundamental reference of the Earth rotation observation by the method of optical astrometry, such as VZT, PZT, astrolabe, transit instrument and so on, relies upon the stellar system. Hence the stellar positions and proper motions, and the celestial reference coordinate system are essential to preserve the system of the Earth orientation parameters determined by the optical astrometry.

One of the main objectives of this paper is to show how the errors in the reference coordinate system, especially the errors in the nutation series, affect the determination of the Earth orientation parameters. Another is to estimate the effect of the nutation errors on the corrections to stellar positions in source catalogs, determined internally by the chain method using the observed latitude and UT0-UTC.

2. Errors in Stellar Positions and the z- and τ-Terms

The observational equations to determine the polar motion (x,y) and the variation of the rotational speed of the Earth (UT1-UTC) from the observed latitude variation and UT0-UTC are:

$$d\phi j = x \cos\lambda_j + y \sin\lambda_j + z , \qquad (1)$$

$$(\mathrm{UT0-UTC})j = \tan\phi j(- x \sin\lambda j + y \cos\lambda_j + \tau) + (\mathrm{UT1-UTC}). \qquad (2)$$

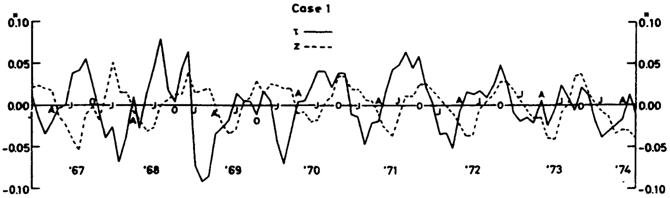

Fig. 1

Case 1: τ and *z* derived from the time and latitude data combined, weighted by $W/2$

H. K. Eichhorn and R. J. Leacock (eds.), Astrometric Techniques, 133–141.

The z- and τ-terms in these equations were introduced by Kimura (1902) and Yokoyama (1976), respectively.

Wako (1970) suggested that Kimura's annual z-term is mainly due to the error of the semi-annual nutation term determined on the basis of a rigid Earth model. In addition, Yokoyama (1976) showed that the similar effect appears in longitude variation as the τ-term in equation (2), with a phase lag of about 90 from the z-term (Figure 1).

Kinoshita et al. (1979) reduced the past ILS observations using two kinds of nutation series; one is Woolard's (1953) series based on a rigid Earth model, and the other is Molodenskij's (1961) series based on a non-rigid Earth model. They examined whether the annual variation in the z-term is eliminated by adopting the nutation series of a non-rigid Earth model. The observation programs of the ILS have been updated seven times. The declination errors of the observed stars were corrected for each program by the chain method. Then the mean values of the z-term were made for each of the twelve months over the period of observation for each program. Some of the results are shown in Figure 2 which are reproduced from the paper by Kinoshita et al. (1979). As is shown in this figure, the annual component of the z-term decreased remarkably by applying the non-rigid nutation series.

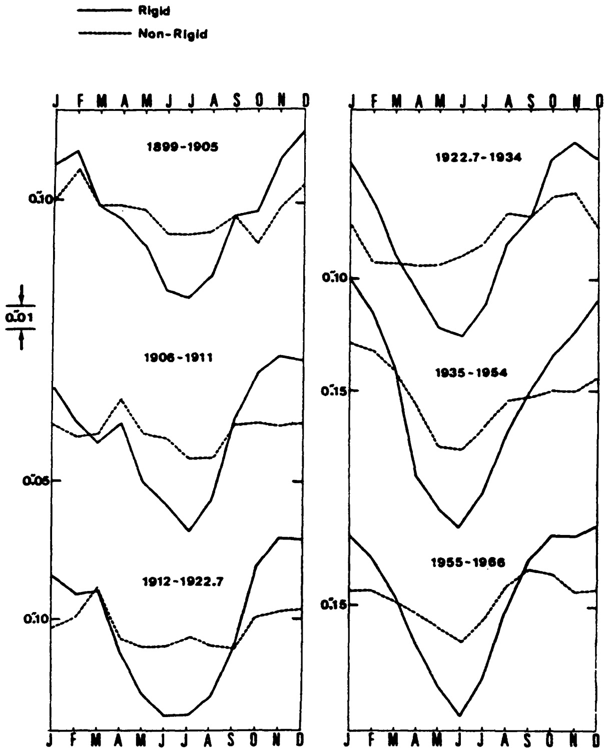

Figure 2. ILS z-term for each month based on the two nutation series.
Rigid: IAU nutation series,
Non-Rigid: Nutation series in table 1 based on Molodenskij's second model.

This means that the main cause of the annual z- and τ-terms are the errors in the nutation series adopted in the IAU (1964) System of Astronomical Constants. This also means that the z- and τ-terms in equations (1) and (2) are not necessary in estimating the Earth orientation parameters from optical astrometric observations, when the IAU 1980 Theory of Nutation is adopted.

The secular trend of the z-term based on Boss' GC and the corresponding value of (GC-MD) are shown in Figure 3 which is reproduceed from the paper by Sato and Wako (1974). The MD catalog compiled by Melchior and Dejaiffe (1969) gives the positions and proper motions of the ILS stars in the FK4 system. The difference of (GC-FK4) in the declination zone from +20°to +60°is also plotted in this figure as a reference. From this figure, we can see that the variations of the mean z, (GC-MD) and (GC-FK4) are parallel. This means that the secular variation of the z-term is due to the proper motion error of the GC. In other words, the secular trend of the z-term well expresses the average proper motion error of the GC.

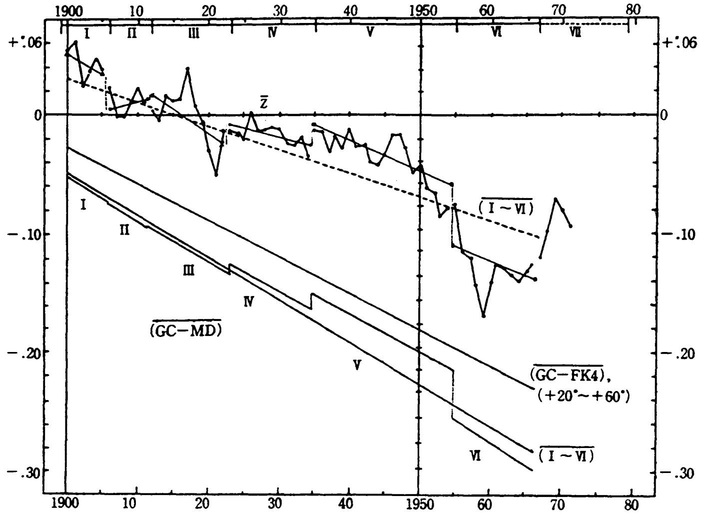

Fig. 3 Annual mean z, (GC−MD), and (GC−FK4).

3. New Astronomical Constants and the Observations of the Earth Rotation

From January 1, 1984 onwards, the new astronomical constants and J2000.0 system are applied to the computation of apparent places of stars used for the observations by the method of optical astrometry. A difference of the apparent places between the new and old systems is shown in Figure 4 for FZT program at Mizusawa, as an example.

Figures 4-a, 4-b, and 4-c show the differences of the apparent declinations of Mizusawa FZT stars (new - old), in which group values (two groups a night) and the daily mean are plotted, for the years 1981, 1982 and 1983, respectively. Some characteristic features are seen in these figures. One is the annual variation with amplitude of about 0"02 ~ 0"03, which is undoubtedly due to the errors of the semi-annual (P = 182.6 days) and principal (P = 6798.4 days) terms coupled with the right ascension of the observed stars. This is the cause of the annual z-term. Another is the short-periodic variation with amplitude of about 0"01 overlapping the annual variation. This is due to the error of the fortnightly term (P = 13.7 days). Given in Table 1 are four main nutation terms whose amplitude differences exceed 0"005.

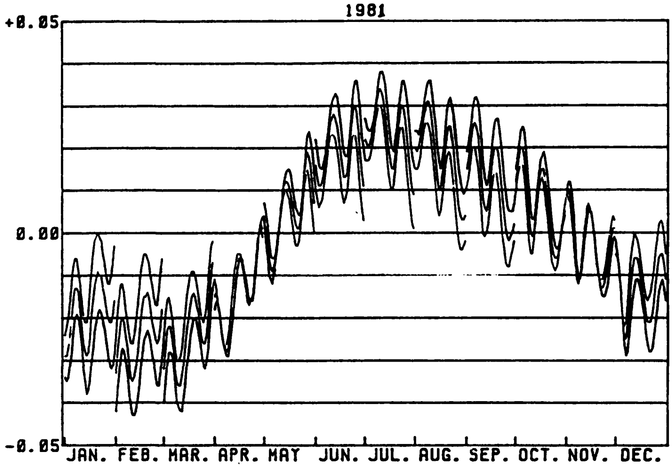

FIG. DIFFERENCE OF APPARENT PLACE (NEW-OLD)
EX. FZT PROGRAM AT MIZUSAWA(TWO GROUP MEANS AND DAILY MEAN)

Fig. 4-a

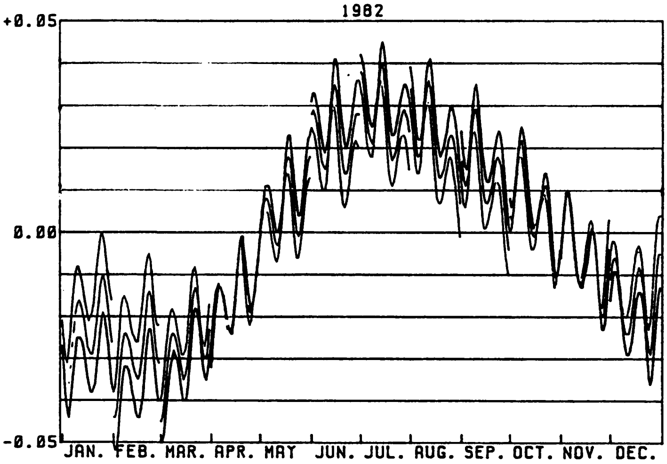

FIG. DIFFERENCE OF APPARENT PLACE (NEW-OLD)
EX. FZT PROGRAM AT MIZUSAWA(TWO GROUP MEANS AND DAILY MEAN)

Fig. 4-b

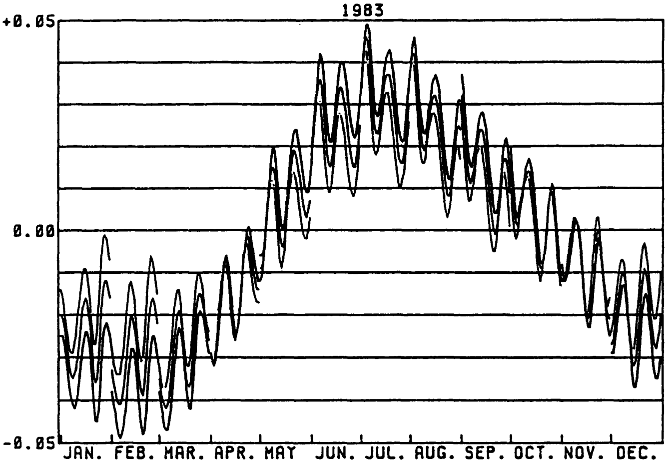

FIG. DIFFERENCE OF APPARENT PLACE (NEW-OLD)
EX. FZT PROGRAM AT MIZUSAWA(TWO GROUP MEANS AND DAILY MEAN)

Fig. 4-c

Table 1. Differences of Nutation Terms [New - Old]

(greater than 0"005)

	P(days)	Long.(0"001)	Obliq.(0"001)
1.	6798.4	50	-8
2.	365.3	17	5
3.	182.6	-46	22
4.	13.7	-24	9

4. Effect of the Errors in the Nutation Series on the Declination and the Right Ascension Corrections Estimated by the Chain Method

In addition to the errors of the celestial reference frame, the observational results by the optical astrometry are considerably contaminated by the position and proper motion errors in source catalogs. These errors have been estimated internally by the chain method using the observed latitude and UT0-UTC. In the course of estimating the internal errors, the nutation errors play an important role and introduce spurious periodic variations in the estimated

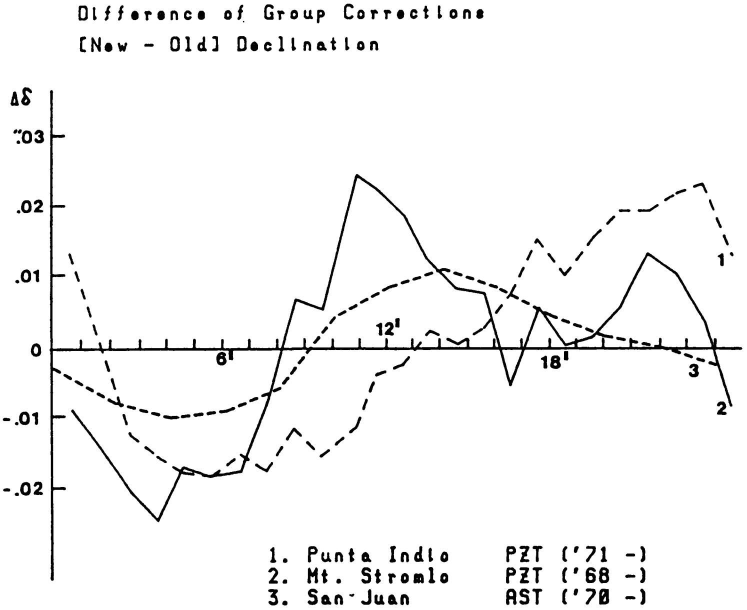
Difference of Group Corrections
[New - Old] Declination
Δδ
".03
.02
.01
0
-.01
-.02
6h
12h
18h
1
2
3
1. Punta Indio PZT ('71 -)
2. Mt. Stromlo PZT ('68 -)
3. San-Juan AST ('70 -)

Fig. 5-a

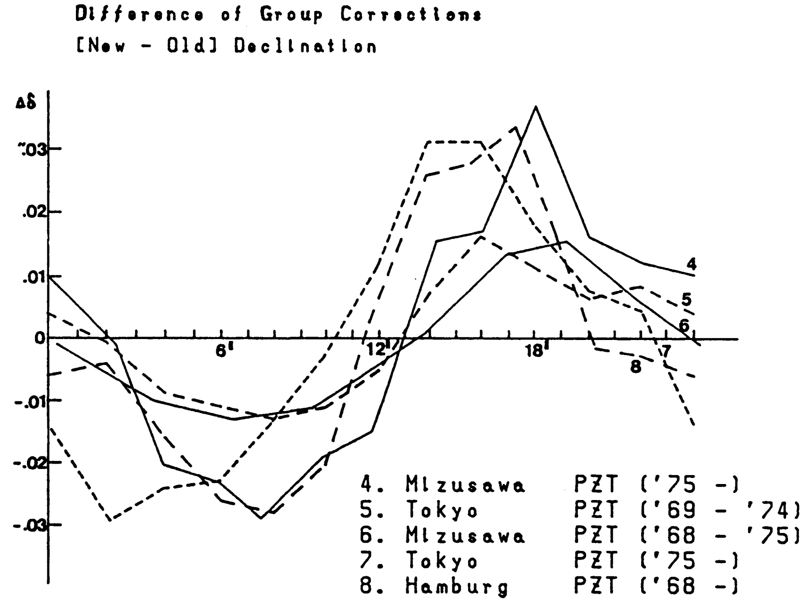
Difference of Group Corrections
[New - Old] Declination
Δδ
".03
.02
.01
0
-.01
-.02
-.03
6h
12h
18h
4
5
6
7
8
4. Mizusawa PZT ('75 -)
5. Tokyo PZT ('69 - '74)
6. Mizusawa PZT ('68 - '75)
7. Tokyo PZT ('75 -)
8. Hamburg PZT ('68 -)

Fig. 5-b

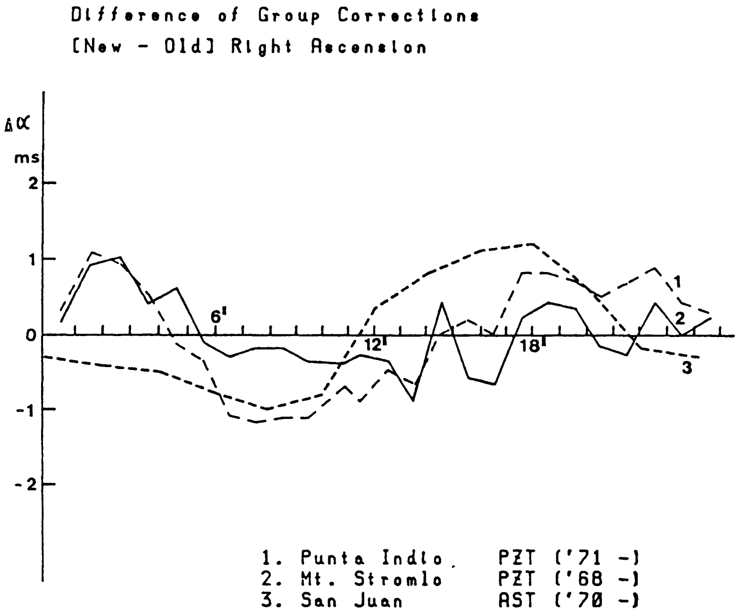
Difference of Group Corrections
[New - Old] Right Ascension
Δα
ms
2
1
0
-1
-2
6ʰ
12ʰ
18ʰ
1
2
3
1. Punta Indio PZT ('71 -)
2. Mt. Stromlo PZT ('68 -)
3. San Juan AST ('70 -)

Fig. 5-c

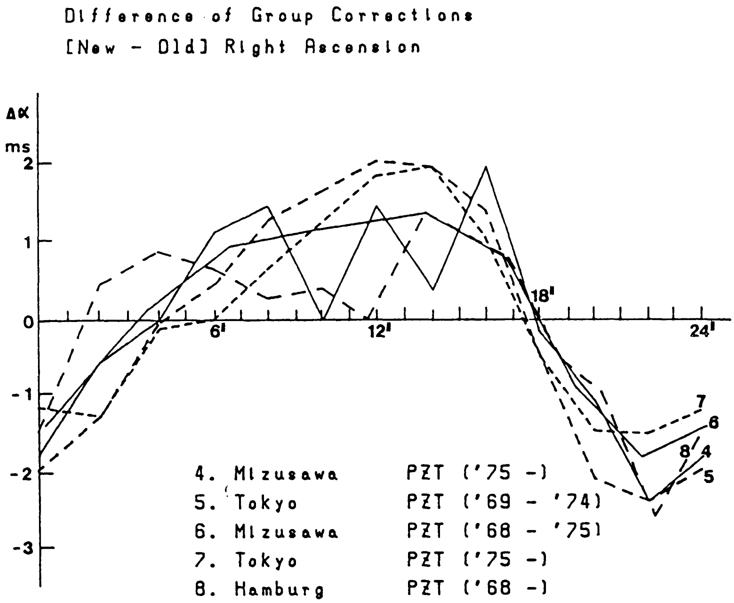
Difference of Group Corrections
[New - Old] Right Ascension
Δα
ms
2
1
0
-1
-2
-3
6ʰ
12ʰ
18ʰ
24ʰ
7
6
8
4
5
4. Mizusawa PZT ('75 -)
5. Tokyo PZT ('69 - '74)
6. Mizusawa PZT ('68 - '75)
7. Tokyo PZT ('75 -)
8. Hamburg PZT ('68 -)

Fig. 5-d

position corrections, depending on the right ascension. For example, Wako (1970) pointed out that the error in the semi-annual nutation with amplitude of about 0."02 is amplified to approximately twice as large as the original error. In other words, this has made it easier to detect the annual z-term from the latitude variation corrected by the declination corrections.

In order to examine the systematic differences of the group corrections estimated in both the new and old systems, the data accumulated at the IPMS were analysed. The latitude and UT0-UTC data reported in the old system were converted to the new system using the IPMS software. Then the group corrections were estimated for the old and new systems, respectively, and their differences were made.

Shown in Figures 5-a to 5-d are several examples of the differences. Figure 5-a shows examples of the southern staions, whereas Figure 5-b of the northern stations, both for the case of the declination. These two figures show in-phase variations. This is reasonable when we consider the effect of nutation error on the declination:

$$d\delta = d(\Delta\psi)\sin\varepsilon\cos\alpha + d(\Delta\varepsilon)\sin\alpha , \qquad (3)$$

where $\Delta\psi$ and $\Delta\varepsilon$ are nutation in longitude and in obliquity, and ε is the obliquity and α is the right ascension of the observed star.

Shown in Figures 5-c and 5-d are similar differences in the right ascension. The features of the group correction differences are quite different between the two hemispheres, namely, the phases are reversed. When we consider the following approximate expression of the effect of the nutation errors on the right ascension, it is easily understood that the phase is reversed due to the factor tan ϕ which takes opposite signs in the two different hemispheres:

$$d\alpha = \tan\phi\,(d(\Delta\psi)\sin\varepsilon\sin\alpha - d(\Delta\varepsilon)\cos\alpha), \qquad (4)$$

where ϕ is latitude of the station.

Thus, it is absolutely necessary to re-estimate the position and proper motion errors of stars observed at each station, based on the new system of apparent places, in order to fully eliminate the errors of the nutation series.

It is inadequate to keep the internal corrections estimated from the data reduced in the old sytstem, even though the astronomical constants are revised.

5. Concluding Remarks

As was discussed in the preceding sections, basic ideas to improve the accuracy of optical astrometric observations of the Earth rotation were presented. Internal corrections are closely related to the adopted nutation series; therefore, it is required that every station re-reduce all the past observations in the new system and re-estimate internal corrections based on such data. This certainly makes it possible to eliminate the systematic errors implied in the stellar system, and enhance the accuracy of the optical astrometric observations of the Earth rotation. However, the internal correction by the chain method never determines the average position and proper motion errors of the adopted source catalogs. This kind of work is the task of high precision astrometry, such as Project HIPPARCOS.

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Discussion:

KOVALEVSKY: Your results show a considerably decreased value for the z-term. Might one regard it as a valid constraint to be put upon a new nutation theory that there should be no z-term? Or is this not reasonable?

SATO: The z-term would indeed become superfluous if we had a perfect nutation theory, if the position and orientation of the Earth were perfectly well known and if we had very precise positions and proper motions.

GUINOT: A new perfect nutation theory could indeed be based on the assumption of a zero value for the z-term. Errors in the positions will, however, even under those circumstances, make it necessary to provide for a nonzero z-term.