THE CONVERSION FROM THE B1950 FK4-BASED POSITION TO THE J2000 POSITION OF CELESTIAL OBJECTS

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We present here the fundamental idea of the conversion method between old and new reference frameworks. Some practical applications are made for the optical observations for Tokyo PZT. The method can be also applied to the conversion of radio sources where we have met a great difficulty in performing the conversion because of no citation of observation epochs in general. We discuss their necessity in order to establish a concrete compilation of the position of the radio sources.

1. INTRODUCTION

At its 17th General Assembly (GA) in 1979, IAU (Trans. IAU, 17B) adopted a resolution such that the UT1 should have the continuous value and rate at the transition epoch of the astronomical constants scheduled at 1984 January 1, 0^hUT. This is necessary because the change in the astronomical constants should not lead to a jump in the value of the UT1 as well as in the rate of UT1 without any change in the physical situation of the rotation of the Earth. Aoki et al. (1982) discussed in details the formula which shall be introduced in order to satisfy the above requirement, taking into account the equinox correction which is scheduled to be introduced in the formation of FK5 (also see Aoki and Kinoshita, 1983). The formula was adopted at the 18th GA of the IAU (Trans. IAU 18B) in 1982.

The standard epoch in the IAU 1976 system is chosen to be J2000 by IAU (Trans. IAU, 16B). The precession constant was also revised in this system. A consistent method to satisfy all the requirements mentioned above was discussed by Aoki et al. (1983).

This paper describes the idea underlying in the paper by Aoki et al. (1983) and its applications for the practical problems.

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2. FUNDAMENTAL IDEA

(1) Time Variation of E-terms of Aberrations

The IAU 1976 system requires that the mean place should be exactly referred to the position seen from the barycenter of the solar system, and the so-called E-terms should be subtracted from the current mean place of stars. In this case, it is noted that the E-terms are not constant but are affected by a time-variation due to the change of the longitude of perihelion and of the eccentricity of the Earth's orbit. The amount is 0."002/cy, and should not be neglected in the case of precise subtraction of E-terms from its current mean place. These effects are virtually mixed in the proper motions of the celestial objects hitherto. Therefore, the proper motions should be corrected accordingly as well as the subtraction of E-terms from the mean place.

(2) Continuity of UT1 Both in Value and in Rate

In order to satisfy this requirement, the equinox correction (Fricke, 1981, 1982) is introduced at the transition epoch (the beginning of the year 1984). The mean position is calculated from the B1950 to 1984 by a transformation matrix of Newcomb, then the equinox correction (including its time variation) is introduced. Finally a transformation matrix of Lieske *et al*. (1977) is introduced to obtain the coordinates for J2000 from the transition epoch, where the position and the proper motion at J2000 are so chosen that the values and the time variations in right ascension and declination be continuous at the transition epoch except for equinox correction, because the change of the rotational speed (caused by the change of the adopted precession constant) will produce the change in proper motion, while the observed position should not be affected by the choice of adopted reference framework.

3. PRACTICAL APPLICATION ON THE COMPARISON BETWEEN THE NEW AND OLD METHODS IN PZT OBSERVATIONS AT THE TAO

The workshop of MERIT held at Royal Greenwich Observatory in May 1983 recommended the change in the reduction method of optical observations from the beginning of 1984 (MERIT Standards, Appendices 1, and 2, 1983 July). The new method consists of (i) the transformation of mean place and proper motions given by Aoki *et al*. (1983), (ii) the aberration strictly referred to the Earth's motion with respect to the barycenter of the solar system, (iii) the precession formulae given by Lieske *et al*. (1977), (iv) the matrix form of the nutation series of IAU 1980 (Seidelmann, 1982), and (v) the relativistic effect in the light path.

The difference between New and Old system in the apparent declinations is given by the top of the Figure 1. As one can easily imagine from the above construction, the most effective change is caused by the

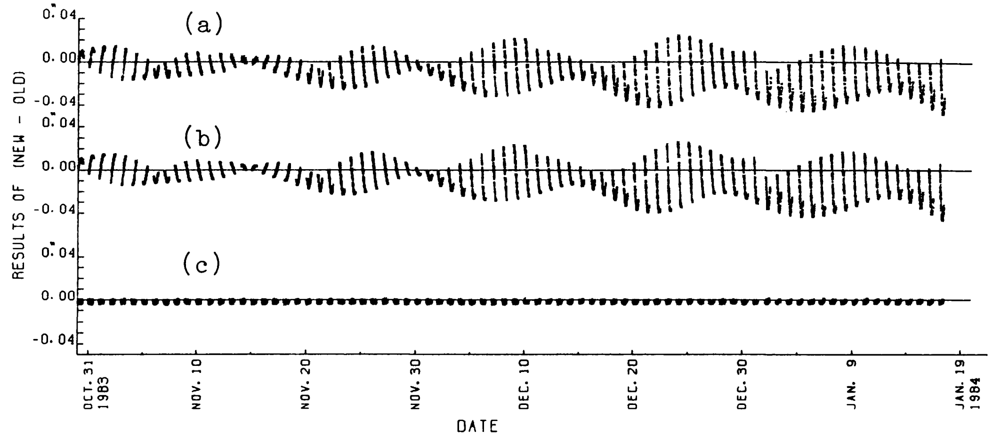

Figure 1. Differences between New and Old systems in apparent declinations for Tokyo PZT programs. (a) New-Old of apparent declinations. (b) New-Old caused by the change of nutations. (c) "(a)-(b)".

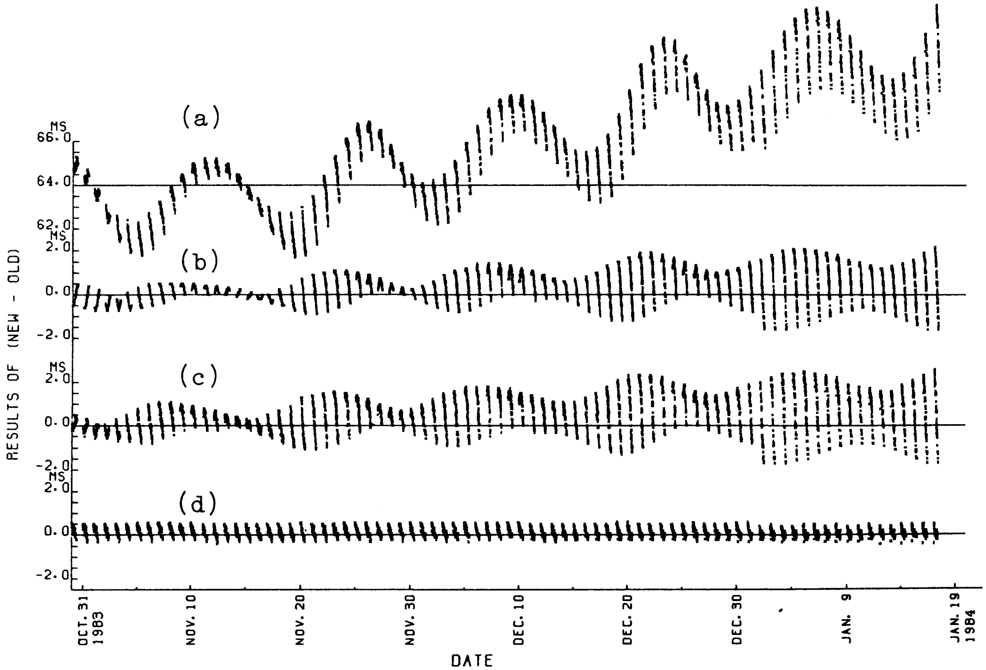

Figure 2. Differences between New and Old systems in right ascensions for Tokyo PZT program. (a) New-Old of apparent right ascensions. (b) New-Old caused by the change of nutations without equation of equinoxes. (c) New-Old of meridian transit times in UT. (d) "(c)-(b)".

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change in nutation which will be given in the second diagram of this Figure. The difference between the two diagrams is given in the third diagram.

Figure 2 shows the comparison of the apparent right ascensions and the difference in UT0. The second diagram shows the difference between the New and Old nutations without the equation of equinoxes, which appears in the difference of UT0 determination. The slight residual given by the bottom diagram which is the difference between the second and third diagram is under the limit of accuracy in the present optical determination, and out of the present consideration.

4. ON THE RADIO SOURCES

The positions of radio sources referred to FK4 (Fricke and Kopff, 1963) framework are inevitably affected by the (virtual) proper motion, if the FK4 framework is not the representation of the inertial framework. In fact, if we assume that the position of an object referred to the new system is unchangable, then the object has the proper motion with respect to the old FK4 system, by the corresponding amount of the difference in precession constants. Moreover, nobody knows exactly so far whether the precession constant by Fricke (1977) gives the position referred to the inertial framework because of the variability of their shapes, and of unknown distances of them. In this respect, the position of the object referred to some framework is no more than of conventional nature. In other words, we can know only the position referred to the framework at certain observation epoch in any case. It is recommended, therefore, to mention it as well as the referred coordination such as B1950 or J2000.

Now, the practical procedure converting the B1950 position to the J2000 position are as follows: (i) the right ascension α and the declination δ referred to B1950 are expressed by the vector representation $\mathbf{r}_0$ in 3-dimensional space, (ii) from which the E-terms of aberration at the observed epoch are subtracted to obtain $\mathbf{r}_1$. (iii) Assuming that the proper motion with respect to the FK4 system are zero, one should apply the conversion matrix given in Aoki et al. (1983) to obtain $(\mathbf{r}, \mathbf{v})$. (iv) The position referred to the J2000 framework at the observed epoch are given by

$$\mathbf{r}' = \mathbf{r} + \text{arc } 1'' \, \mathbf{v}t,$$

where t is the Julian century of observation epoch elapsed since J2000. The α and δ obtained from the vectorial representation $\mathbf{r}'$ represent the values for the position at the observation epoch referred to the J2000 framework (see appendix 2 of Aoki et al., 1983, also note that this procedure revises the corresponding statement in MERIT Standards, appendix 1). It is noteworthy that the above procedure is of mathematical convenience, since the result coincides with that obtained from the assumption of no proper motion with respect to the FK5 system.

On the other hand, the above procedure is (practically) equivalent to the following procedures: (i) α and δ referred to B1950 are transformed to the position at the observation epoch under assumption of taking Newcomb's precession and of taking zero values for the proper motions in respective directions. (ii) the E-terms at the observation epoch are subtracted, and the equinox correction at the observation epoch is applied. (iii) The conversion is applied from the observation epoch to J2000 using the precession of 1976 IAU system under an assumption of no proper motion.

It is noted that, if conversely the compiled catalogue for B1950 from the observed epoch does not take the assumption of using Newcomb's precession and zero-values for proper motions, the above procedure will fail. In such case, the adopted precession constant and adopted assumption of the proper motion should be applied in (i), in order to recover the position at the observation epoch. However, in some existing catalogs, we could not find any explicit comments on the adopted precession constant (e.g. JPL 1980-1). It is also noted that the (mean) observed epoch is indispensable even for the compiled catalog of radio sources in order to fix the position with respect to the adopted framework.

5. EXAMPLES

(1) Comparisons of Our Result to Those Adopted in Current VLBI Catalogs

We can show some examples of comparing our results to those by others, because in some catalog the right ascension of 3C273B is adopted as a defined value. A recent catalog of VLBI radio sources by NASA for CDP (Crustal Dynamics Project) adopts a defined right ascension of 3C273B, $12^h29^m06\overset{s}{.}6997$ (J2000). This value has been derived by a theoretical conversion to J2000 from the previously defined B1950 value, $12^h26^m33\overset{s}{.}246$ (B1950), which firstly adopted by Clark et al. (1976) (C.Ma et al., 1982). This convention is recommended by Elsmore (1979), and adopted in many catalogs (e.g. JPL 1982-4 (Fanselow et al., 1983) or Witzel and Johnston, 1982).

However, there seems to be some confusions in the interpretation of the original value given by Hazard et al. (1971). In the first two rows of Table 1 we show two values of right ascension for 3C273B. The difference between the two values is $0\overset{s}{.}002$ which is equivalent to the E-term for 3C273B in right ascension (exactly $0\overset{s}{.}0018$). The value given by Hazard et al. is determined from the lunar occultation and photographic observations, and they give no remark on E-term. But if they used a standard almanac for reducing their apparent places, the derived mean place ought to include E-term according to the former IAU resolutions (Trans. IAU, 8). Thus we regard it as with E-term (row 1). However, Clark et al. (1976) regarded it as without E-term (row 2). This is succeeded by Elsmore (1979), NGS (Robertson and Carter, 1982) and JPL (Fanselow et al., 1983). On the contrary, Witzel and Johnston (1982) assumed that the value contains the E-term.

row \ column	1	2	3	4
	B1950 α (with E-term)	observation epoch	J2000 α our results	J2000 α other's
1	12 26 33.246 Hazard et al. (1971) Witzel & Johnston (1982)	1965.43 (assumed)	12 29 06.69758	12 29 06.6997 C.Ma et al.(1982) (NASA CDP) NGS "POLARIS" Fanselow et al. (1983) (JPL 1982-4) (JPL 1983-3)
2	12 26 33.248 Clark et al. (1976) Elsmore (1979) Robertson & Carter (1982)	same	12 29 06.69958	
3	12 26 33.247 Wade & Johnston (1977)	1975.4	12 29 06.70018	12 29 06.655 Wade & Johnston (1977)
4	12 26 33.250 de Vegt & Gehlich (1981)	1975.0 (assumed)	12 29 06.70311	
5	12 26 33.2380 Harrington et al. (1983)	1980.12	12 29 06.69193	
6	12 26 33.24769(α) 02°19'43".4238 (δ) Fanselow et al. (1981) (JPL 1980-1)	1978.62 (assumed)	12 29 06.70137 02°03'08".7107	12 29 06.69970 02°03'08".5917 Fanselow et al. (1983) (JPL 1982-4)

Table 1. Recalculations of J2000 Right Ascension of 3C273B

The results of our calculations are shown in column 3 of Table 1 for both cases. Unfortunately they are not precise in the strict sense because Hazard et al. did not give a mean observation epoch. We presumed it June 7, 1965, which is referred to as that of "the most reliable occultation observation". The results show that the presently adopted value of J2000 right ascension of 3C273B, $06^{s}.6997$, coincides with the row 2 case, which has problem according to our opinion.

(2) Comparison with J2000 Values Calculated by Wade and Johnston (1977)

In row 3 of Table 1 we show a value given by Wade and Johnston (1977) which is determined in such that their system of right ascensions is consistent with that of Clark et al. (1976). They clearly describe their mean observation epoch and about the E-term, and it provides a good example for our calculation. However, our J2000 value is shown in column 3 of row 3 of the Table, and that calculated by Wade and Johnston in column 4, giving considerably large difference with ours. This difference is likely to be attributed to their neglection of the equinox correction at the observation epoch (i.e. $0^{s}.056$).

(3) New Values of Right Ascension of 3C273B in the FK4/5 System

Recently more elaborate values of right ascension of 3C273B determined photographically in the FK4 system are given by de Vegt and Gehlich (1981) and by Harrington et al. (1983). There are no citations on the E-terms in both publications. However, we can infer that they include it, from seeing the numerical values. We have also assumed that the mean observational epoch of the former is 1975. The value by de Vegt and Gehlich (1981) seems to have superior quality to those of Hazard et al., and they should be used as the reference for the future investigations.

(4) Comparison of Two JPL Catalogs of Radio Sources

As shown in row 6 of Table 1, we tried to convert the JPL 1980-1 catalog (Fanselow et al., 1981) from B1950 to J2000, and to compare it with those given in JPL 1982-4 (Fanselow et al., 1983). Since these two catalogs are compiled independently from the original observational data, and since the origins of their right ascensions are defined differently, we cannot compare directly the places of 3C273B. In fact, the result gives a systematic difference in declination [(converted 1980-1) minus (1982-4)],

$$\Delta\delta \approx 0''.11 \cos\alpha .$$

This shows that they have used the different (but unknown) precession constant from Newcomb when they transform the observational data to the B1950 epoch; this was also pointed out by de Vegt and Gehlich (1981, 1982).

6. CONCLUSION

In the field of optical astrometry, we have the common reference of the UT1 and celestial coordinates given by the above system of J2000.

On the other hand, in the field of VLBI-observations and reductions, it seems that there are so many independent constants and reference frameworks. In some cases, we could not know the adopted constants. In such cases, we could not interpret the meaning of the present numerical values. We scarecely inferred them under some assumptions.

In order to establish a more standard reference system, it is necessary to use the common base such as IAU system, or at least to mention the adopted constants if deviated. The IAU system of astronomical constants is no more than a conventional reference frame on which we account the O - C of the constants only after analyzing the observation data.

J2000 framework we have constructed is the reference framework using Fricke's precession constant. If we measure the positions of a radio source referred to this framework at considerably different epochs, then we can know the proper motion referred to this framework. From knowledge of positions of at least 3 sources, we can discuss the mutual rigidity and the rotation of the adopted framework with respect to the radio source system. Only at this stage we can discuss to revise the precession constant.

Therefore, it is recommended to specify the adopted reference framework and adopted constants and its observation epoch even for the radio sources in order to avoid unnecessary confusion.

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Discussion:

HERRING: The right ascension origin of VLBI catalogues is arbitrary because only observations of extragalactic radio sources have been used in analyzing these data. The current catalogues can have an arbitray change in right ascension applied to them when a better match between the optical and radio catalogue right ascension origins is known.

JOHNSTON: We just revised the right ascension of 3C273 to line up with the positions given by lunar occultations.

STRAND: Can you explain how you can justify giving your reduction of original observations with 3 decimal places to results with 5 decimal places in the seconds of time?

WESTERHOUT: Let me clarify what Dr. Aoki has been saying: He uses his algorithms to go from B1950 to J2000 and compares his results with those of other authors, who used different algorithms for the same transformation. Since they are different, the results are different. Dr. Aoki points out that all should use the same algorithm. Of course, it is immaterial whether 3C273B is the RA zero point; the only thing he is testing is the conversion algorithm. As an aside; in his table, Dr. Aoki shows Wade and Johnston (1977) with a J2000 position. This is of course a B2000 position, as J2000 had not yet been invented in 1977.