Comparison of the Effect of Various Solar System Ephemerides on Equator and Equinox Solutions from Six-inch Transit Circle Observations of the Sun

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ABSTRACT

Using observations of the sun made with the Washington six-inch transit circle from 1911 to 1971, equator and equinox corrections based on Newcomb's, DE102, and DE200 ephemerides are given for each of six catalogs of results of observations made during that period. Each of these catalogs was observed and discussed fundamentally, that is, in such a way as to decouple the system of the catalog positions from dependence on previously given systems of catalog positions and proper motions.

Variations of the solutions for the equator and equinox corrections and of earth orbital parameters including corrections to the ephemeris mean longitude of the sun, the mean obliquity of the ecliptic, the mean longitude of perihelion, and the mean eccentricity of the earth's orbit are discussed for solutions based on the independent catalog systems and on the catalog systems referred to the FK4 and to an improved FK4 in which an epoch dependent correction to the right ascension zero point has been applied.

INTRODUCTION

Results discussed in this paper come from a larger discussion to compare observations of solar system objects made with the Washington six-inch transit circle from 1911 to 1971 with several different solar system ephemerides to determine what differences, if any, occur in the solutions for the observed equator corrections, $\Delta\delta_o$, and the observed equinox corrections, E_o, of the stellar catalogs associated with the observations of the solar system objects.

The present discussion involves only observations of the sun. The full solution also gives corrections to the mean longitude of the sun, ΔL, the mean obliquity of the ecliptic, $\Delta\epsilon$, the mean longitude of perihelion, $\Delta\pi$, and the mean eccentricity of the earth's orbit, Δe. These solutions have been made for the catalogs individually and taken together, and in solutions for the constant corrections only and also for a modified solution in which time rates of change of the six constants have been introduced into the observation equations. The catalogs from which the data have been taken are the W10, W25/W50, W2/50, W3/50, W4/50 and W5/50. The three solar system ephemerides which were selected for comparison with the observations were Herget's solar coordinates 1800-2000 based on Newcomb's

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Tables of the Sun (NEWCOMB(Herget)), and the Jet Propulsion Laboratory's Development Ephemerides 102 and 200 (DE102 and DE200). The DE102 reference frame has been re-oriented by us to the FK4 system at B1950.0 as described by Newhall *et al.* 1983. The other ephemerides have been used as they were given, except that Newcomb's precession was used to refer the NEWCOMB(Herget) and DE102 ephemeris positions to the equinox of date; for DE200, the Lieske *et al.* 1977 precession was used.

The catalog reference frames adopted for this study were 1) the instrumental catalog system of each individual catalog, 2) the FK4 system, and 3) an improved FK4 system. The third system (IMPROVED FK4) was generated from the FK4 system by adding terms to the FK4 right ascensions and proper motions in right ascension to correct the equinox of the FK4 as described by Fricke 1982. Observations referred to the FK4 system were compared with the NEWCOMB(Herget) and DE102 ephemerides. Observations referred to the IMPROVED FK4 were compared with DE200. Observations referred to the instrumental catalog systems were compared with each of the three ephemerides.

In every case, solutions have been made with and without the ΔT corrections for the difference between the Ephemeris and Universal Time scales. This was done to test the sensitivity of the solutions to the adopted time scale. Altogether, twelve types of solutions were made. Only a few of the solutions can be discussed here.

OBSERVATION EQUATIONS FOR THE SUN

The observation equations in right ascension and declination are:

$$(O-C)_\alpha = -E_o + \cos\epsilon \sec^2\delta\, \Delta L - \cos\alpha \tan\delta\, \Delta\epsilon + 2 \sin\alpha \sec\delta\, \Delta h - 2 \cos\alpha \sec\delta \cos\epsilon\, \Delta k,$$

$$(O-C)_\delta = -\Delta\delta_o + \cos\alpha \sin\epsilon\, \Delta L + \sin\alpha\, \Delta\epsilon + 2 \sin\delta \cos\alpha\, \Delta h - 2 \cos^2\alpha \cos\delta \sin\epsilon\, \Delta k,$$

where $\Delta e = \Delta h \cos\pi + \Delta k \sin\pi$ and $e\Delta\pi = -\Delta h \sin\pi + \Delta k \cos\pi$.
Δh and Δk are corrections to $h = e \cos\pi$ and $k = e \sin\pi$, respectively.

"O" is the observed coordinate referred to one of the reference frames. "C" is the corresponding coordinate from one of the three ephemerides, referred to the time of meridian passage over the assumed longitude of the Washington six-inch transit circle. The number of observations of the sun in most catalogs ranges from 800 to 1000 in each coordinate, except for W25/W50 which included about 2300 observations in each coordinate. The total number of observations in both coordinates is about 13,300, with about 6600 in right ascension and 6700 in declination. Some of the results emerging from the study are as follows:

EQUATOR CORRECTIONS

Equator corrections are not significantly affected by the application of ΔT corrections.

Each of the three ephemerides gives nearly identical equator corrections regardless of the system to which the observations are referred.

All equator corrections are negative. For observations prior to 1950,

the equator corrections are of the order of 0.3 to 0.5 arcsec. Since 1950, they seem to be less affected by systematic errors of observation, and are of order 0.1 to 0.2 arcsec.

EQUINOX CORRECTIONS

Equinox corrections are not significantly affected by the application of ΔT corrections.

The observed equinox solutions based on DE102 are consistently about 0.5 arcsec less than those based on the NEWCOMB(Herget) ephemeris in each catalog. This relative difference is independent of the system to which the observations are referred. In the instrumental catalog system, equinox corrections based on DE200 and NEWCOMB(Herget) are nearly equal. They differ by less than the average mean error of the determinations which is about 0.07 arcsec.

This implies that a very careful choice of ephemeris must be made in any work where the object is to determine an observed equinox correction to be applied to the stellar observations made concurrently with observations of solar system objects. We are concerned about equinox solutions from adopted minor planet ephemerides which should in principle yield an observed equinox independent of the adopted ephemeris, but which in practice may not. This point deserves further study.

CORRECTIONS TO THE MEAN LONGITUDE OF THE SUN

Corrections to the mean longitude of the sun do not depend significantly on the system to which the observations are referred.

The solution for the correction to the mean longitude of the sun is highly sensitive to whether or not ΔT is applied, as expected.

With ΔT applied, the solutions for ΔL based on observations referred to FK4 and compared with NEWCOMB(Herget) never differ from zero by more than 0.1 arcsec for any catalog. There appears not to be any significant time rate of change from 1911 to 1971. In the case of DE102, the ΔL solutions are systematically more negative than NEWCOMB(Herget) by about 0.18 arcsec with no indication of a time rate of change. In the case of DE200, there is a systematic decrease of ΔL of about 1 arcsec per century as one moves from the earliest to the most recently observed catalogs.

To formalize this result, the observation equations were modified to include as unknowns the time rates of change of the six unknowns previously treated as constants. That is, a term of the form $\Delta\dot{L}\ (T-T_0)$ was added to ΔL, and similarly for each of the other five unknowns. T_0 is the average epoch of observation, 1942.35. Then the 13,300 (O-C)'s in right ascension and declination from all six catalogs were used simultaneuosly in a least squares solution for constants and their time rates of change. The solution for ΔL was 0.056 ± 0.033 arcsec and the rate of change, $\Delta\dot{L}$ was -1.04 ± 0.20 arcsec per century, thus confirming the earlier impression from the catalogs treated separately. This unexpected result has not yet been explained.

CORRECTIONS TO THE MEAN OBLIQUITY OF THE ECLIPTIC

Solutions for this correction are insensitive to whether or not ΔT

is applied and are independent of the system to which the observations are referred.

All corrections to the obliquity are negative and they average about -0.2 arcsec. The meaning of this result is not clear. It may reflect inadequacy in the reduction of day observations to the nighttime system. An analysis of observations of other solar system objects especially Mercury, Venus, Mars and Jupiter from the point of view of instrumental behaviour would be useful in this connection.

CORRECTIONS TO THE MEAN LONGITUDE OF PERIHELION

The solutions for this correction are relatively sensitive to the non-application of ΔT. They are always more negative than the values from the solution with ΔT applied, by an amount well correlated with the mean epoch of observation, and they range from 0.5 arcsec for the earliest catalog to about 1.5 arcsec for the latest one.

The average correction to the NEWCOMB(Herget) longitude of perihelion is very large at about -7 arcsec. The average corrections to DE102 and DE200 are significantly smaller and nearly equal at about -2 arcsec. Although the solutions from a particular catalog are independent of the system to which the catalog observations are referred, the W5/50 catalog gives solutions in all three ephemeris cases which differ markedly from each of the other catalogs. This is the only unknown for which a solution from the W5/50 observations behaves in a bizarre way. We are reviewing the W5/50 reduction procedures in the hope of finding the reason there.

CORRECTIONS TO THE MEAN ECCENTRICITY OF THE EARTH'S ORBIT

The solutions for this correction are not at all sensitive to the application or not of the ΔT correction; nor is there any dependence on the system to which the observations are referred.

For NEWCOMB(Herget), we find $\Delta e = -0.15 \pm 0.01$ arcsec. For DE102, $\Delta e = -0.01 \pm 0.01$ arcsec and for DE200, $\Delta e = -0.02 \pm 0.01$ arcsec.

CONCLUSIONS

Contrary to expectations, the observed equinox correction to a catalog system depends on the choice of ephemeris.

We find that when sun observations are compared with DE200 that a secular rate of the mean longitude of the sun is found such that the DE200 decreases by 1.04 arcsec per century with respect to the observations. The same result is obtained regardless of whether the sun observations are referred to the instrumental catalog system or the IMPROVED FK4 system.

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