SECULAR VARIATIONS IN OPTICAL OBSERVATIONS OF PLANETS

SUMMARY

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The conversion in 1984 from constants, reference frames, time scales, and ephemerides, all essentially based on theories and constants by Newcomb, to the IAU 1976 system of constants, new definitions of time scales, FK5 reference system, and integrated ephemerides has produced the expected accuracy improvements. These changes included a correction to the precession constant of 1.13 arcseconds per century, a correction to the equinox motion of the FK4 of 1.23 arcseconds per century, and a new expression for the Greenwich Mean Sidereal time.

There are now some indications of inconsistencies somewhere in the new system. The paper by Stumpff and Lieske (1984) indicated, based on theoretical investigations, that there was a one arcsecond per century discrepancy someplace. They hypothesized that this discrepancy was due either to the new precession constant being wrong, Newcomb's expression for the longitude of the Sun being in error, or that the integrated ephemerides are not inertial, but are rotating with respect to a fixed frame. Krasinsky *et al.* (1986) compared the optical observations to the integrated ephemeris, DE200, and concluded that there was a one arcsecond per century discrepancy between the observations and the ephemerides. Yao and Smith (1988) compared the observations of the Sun, as made with the transit circle in Washington, with ephemerides. They concluded these observations agreed with the theory of Newcomb, but they had a one arcsecond per century difference from DE200. Krasinsky *et al.* (1992) published a more thorough comparison of meridian-circle observations with radar-ranging-based ephemerides. They solved for corrections to the pre-1984 system. These corrections are: to the precession constant, 0.21 ± 0.13 arcseconds per century, to ΔT, -14.5 ± 2 seconds of time per century, and to the equinox motion, 0.78 ± 0.40 arcsecond per century. Smith and Yao (1991) used observations of the Sun, both from Washington and the Cape, to determine a correction to the FK4 equinox of 0.878 ± 0.164 arcsecond per century and a correction to the longitude of the Sun in DE200 of -0.710 ± 0.158 arcsecond per century. Thus, there seems to be evidence that comparisons of the optical observations with the new integrated ephemerides, which for the inner planets are primarily based on radar observations, indicate a difference of approximately one arcsecond per century somewhere in the system.

Bretagnon and Simon (1991) have determined the mean elements for the planets by fitting their general theories of planetary motion to the ephemeris DE200. Standish (1991) has performed a fit of a set of mean elements to the integrated ephemeris positions. A comparison was made between these elements and Newcomb's elements. Comparing Bretagnon and Simon's mean motions, relative to the equinox of date, with those of Newcomb, discrepancies were found that were

S. Ferraz-Mello (ed.), Chaos, Resonance and Collective Dynamical Phenomena in the Solar System, 49–51.

approximately proportional to the mean-motion ratios, thus indicating the discrepancy could have a source based on the time system.

Comparing both Bretagnon and Simon's and Standish's sidereal mean motions of J2000 with those of Newcomb's, there is an indication that Newcomb's sidereal mean motions require equinox corrections similar to those required by the FK4. This could be expected because the equinox determinations of the star catalogs underlying the FK4 were the same equinox determinations used by Newcomb for his theories for the Sun, Mercury, and Venus. Comparisons of the expressions of the mean longitude of the Moon, as determined by Chapront-Touze and Chapront (1988), with that of the Improved Lunar Ephemeris (1954), indicate a linear difference of approximately 1.6 arcseconds per century and a quadratic term.

Consider the problem with the times first. Currently, ephemeris time is defined based on the Sun's position in 1900 and an ephemeris second defined as a fraction of the tropical year for 1900. This definition is based on Newcomb's theory of the Sun and requires the determination of a geometric mean longitude of the Sun and a tropical year defined by the old constants. In practice, ephemeris time, which is needed as a time scale for use before 1955, when atomic time first became available, should be defined based on its needs and uses. In other words, it should be tied with an epoch defined in terms of the beginning of atomic time and with the SI second.

Since this does not explain the discrepancies, let us further examine the question of the times of transit circle observations of solar system bodies. Transit circles traditionally do not use independent clocks for timing observations. The sidereal time of the transit of the object is the observation in the right ascension coordinate. For solar system bodies a time must be determined to record the observation and to evaluate a computed position from the ephemeris. This time of observation on the date is computed iteratively to be the Terrestrial Dynamical Time when the local sidereal time equals the apparent right ascension of the body from the ephemeris being used. In converting from the system based on Newcomb to the new system, the equation for sidereal time was corrected for the equinox motion between the FK4 and the FK5, so that UT1 would be continuous. The change in the precession constant was compensated for by changing the proper motions of the stars. However, the planetary ephemerides by Newcomb were given in terms of the equinox of date, so the expressions incorporated both the motion of the equinox and the precession constant. These ephemerides and the old precession constants were used for observation reduction. The new ephemerides are computed on the fixed equinox of the FK5 and the new precession constant is used to compute apparent places. Thus in computing the times of transit circle observations on the new system, the correction for equinox motion, but not the change in the precession constant, has been included in the local sidereal time, while the ephemeris positions have been corrected for both changes. Therefore, a correction must be introduced into the method of calculating the times of transit circle observations of solar system bodies for the new system.

In summary, the discrepancy discovered by Stumpff and Lieske can be explained by the fact that Newcomb's sidereal mean motions are affected by the equinox motion. The discrepancies found by Krasinsky et al. and by Yao and Smith between

https://doi.org/10.1017/S0074180900090938 Published online by Cambridge University Press

observations and the integrated ephemerides appear to be due to the method of determining the times of the transit circle observations in the new system.

For future use, the definition of ephemeris time should be revised to be consistent with the new system of ephemerides and the time scales based on atomic time. A more extensive paper on this subject is in preparation and will be published separately.

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Discussion

S.Ferraz-Mello – I would like to know if these corrections, or any other foreseen correction, could change significantly the present residuals of the observations of Uranus and Neptune so as to change completely the results obtained when they are interpreted as due to a tenth planet.

P.K.Seidelmann – If the residuals of Uranus and Neptune were secular functions of time, they would be absorbed by corrections to the mean motions. Thus, corrections due to equinox motion or to ΔT will not change the residuals. The one possible correction that might affect the residuals would be the complex periodic corrections from the FK4 to FK5 star catalog, but I expect that these corrections are too small to significantly change the residuals.

https://doi.org/10.1017/S0074180900090938 Published online by Cambridge University Press