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How Do Earth Tides Affect Astronomers?

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Earth tides affect astronomical observations of the Earth's rotation in two ways. They deflect verticals and change the polar moment of inertia of the Earth, thus causing periodic variations in its rotation rate (Table 1). Since astronomers observe stars usually around midnight at almost the same local sidereal time $\alpha = L_{\odot} + 180°$ in every station, where $L_{\odot}$ is the mean longitude of the Sun, the diurnal and semidiurnal tides, as well as nutations, produce apparently common variations with long "aliased" periods in the daily mean latitude and time values of different stations. Therefore, detection of polar motions is little contaminated by the Earth-tide effects, because they are largely absorbed in "common" z, τ and n-terms in the conventional observation equation:

$$\text{latitude:}\quad \Delta\phi = x\cos\lambda + y\sin\lambda + z$$

$$\text{time:}\quad \omega(\text{UTO-UTC}) = \tan\phi(x\sin\lambda - y\cos\lambda + \tau) + n$$

where x, y are "pole coordinates", ϕ, λ are latitude and east longitude of a station and ω is the mean rotation rate of the Earth. Nutation observations, on the contrary, are disturbed rather seriously by the diurnal tides with the same arguments and, through the aliasing, by semidiurnal and long period tides.

A major concern of astronomers in analysing the nutations is to detect evidence for the fluid-core resonance. Observed values contained in the squares of Figure 1 seemingly follow a theoretical resonance curve based on a realistic Earth model. Effects of the diurnal tides in time and latitude expected in $\phi = 39°08'$ (latitude of 5 ILS stations) are shown by the arrows in Figure 1 under the assumption $\Lambda = 1 + k - \ell = 1.2$. It is evident that O_1 and P_1 tides may deviate the observations of the fortnightly and semiannual nutations noticeably. It does not seem appropriate, however, to correct astronomical data for the diurnal-tide effects by simply assuming $\Lambda = 1.2$, because ocean-tide effects must hardly be negligible. The problem may become important in more detailed studies of the internal constitution of the Earth by means of nutation observations.

Consequences of the oscillations of the verticals due to M_2-tide can be observed in the astronomical latitude and time data and are regarded as one of the means for determination of the Λ-factor. In order to decide, for example, that $\Lambda = 1.2$ but not 1.1, however, one needs accuracy higher than 0.001 arcseconds or 3 cm. It does not seem easy, in general, to attain such accuracy by conventional astronomical observations with the typical error of single observation reaching 0.2 arcseconds or 6 m. As a matter of fact, 52 determinations of the Λ-factor so far obtained

TABLE 1. Effects of Earth Tide on Astronomical Observations

	Irregularities in the Earth's Rotation		
	Polar motion	Nutation	Changes in L.O.D.
Latitude	$x(t)\cos\lambda + y(t)\sin\lambda$	$\sin[L(t) - \alpha]$	———
Time	$\tan\phi[x(t)\sin\lambda - y(t)\cos\lambda]$	$\tan\phi\ \cos[L(t) - \alpha]$	$n(t)$

	Earth Tide Effects			
	Long period tide		Diurnal tide Vert. defl.	Semidiurnal tide vert. defl.
	Vertical deflection	Changes in C		
Latitude	$\Lambda\sin2\phi\cos L(t)$	———	$\Lambda\cos2\phi\sin[L(t) - \alpha]$	$\Lambda\sin2\phi\cos[L(t) - 2\alpha]$
Time	———	$k\ \sin L(t)$	$\Lambda\tan\phi\cos[L(t) - \alpha]$	$\Lambda\sin[L(t) - 2\alpha]$

$\Lambda = 1 + k - \ell$

L(t): Argument of periodic disturbance due to the Sun and Moon

α : Local sidereal time

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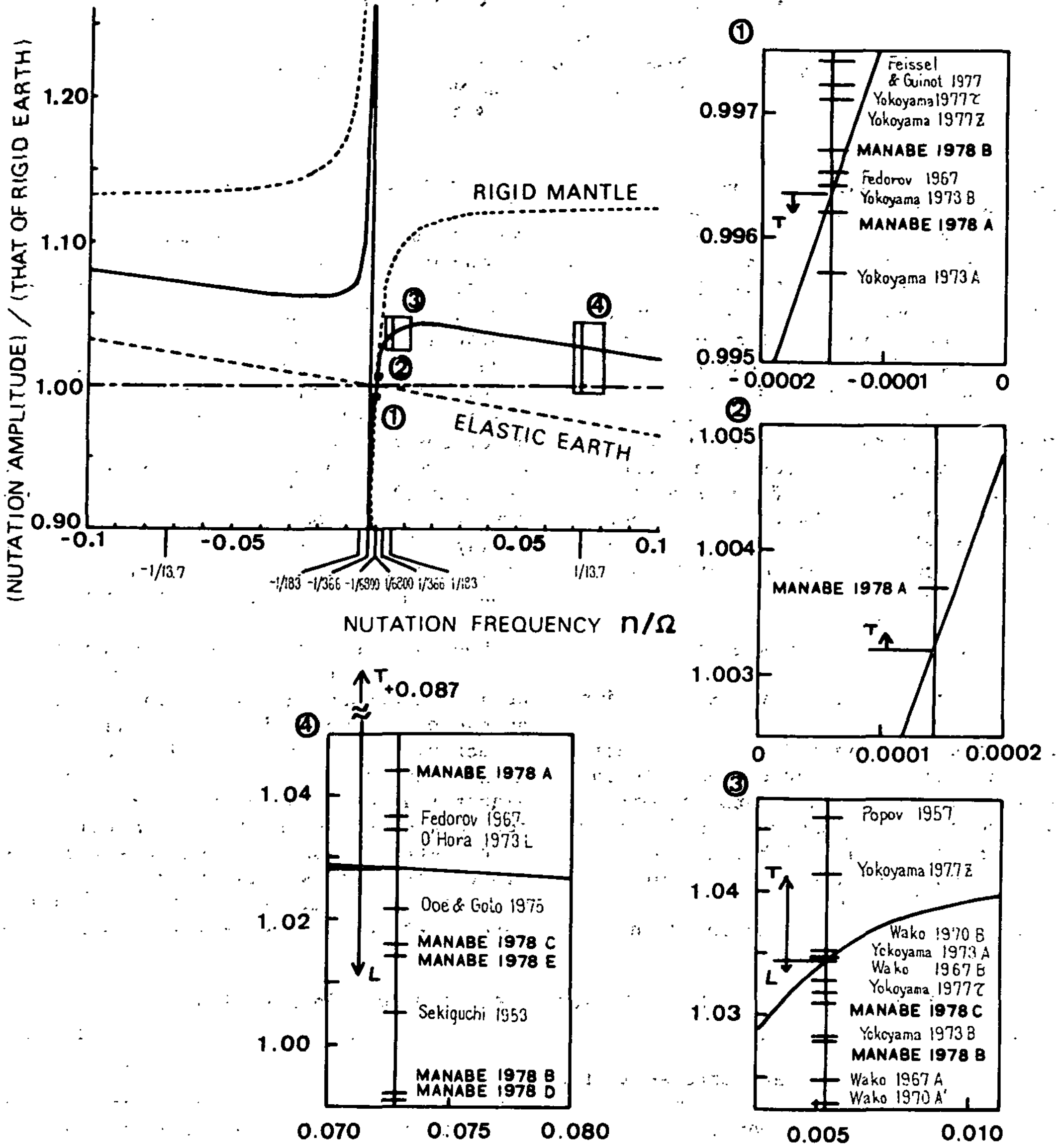

Fig. 1. Effects of diurnal Earth tides on nutation observations. Arrows T and L show the effects of diurnal tides on main nutation components in time and latitude observations, respectively, calculated for $\phi = 39°08'$ with an assumption $1 + k - \ell = 1.2$.

are scattered from 0.1 to 2.3, as shown in Figure 2. Although some authors have pointed out the possible secular change in the Λ-factor, recent analysis of past ILS data done by Manabe, Sakai and Sasao has revealed no firm evidence for the change (Figure 3). Different values of the Λ-factor detected in different stations are sometimes attributed to the difference between oceanic and continental stations. However, deviation of the 18.6-year principal nutation from Woolard's value derived by Manabe et al. from latitude data of 5 ILS stations shows even larger station-to-station differences than those of the M_2-tide (Figure 4), though the principal nutation must almost be unaffected by ocean-tide effects. It thus seems necessary to examine carefully the scale value problem and other possible sources of instrumental errors before considering any inverse problems for the ocean-tide effects on the basis of the astronomical M_2-tide data.

Changes in the rotation rate of the Earth due to zonal deformation caused by M_m and M_f tides are analyzed so as to determine Love number k. It should be noted that one needs 0.001 arcseconds accuracy again in order to decide whether $k = 0.30$ or 0.27. Nevertheless, the reported difference between k-numbers derived from M_m and M_f waves appears significant (Table 2). It might be interesting to note here a possibility that the M_f-wave is disturbed by the aliased "uncorrected" part of the fortnightly nutation arising from the fluid-core effect, which does not seem to have been taken into consideration fully.

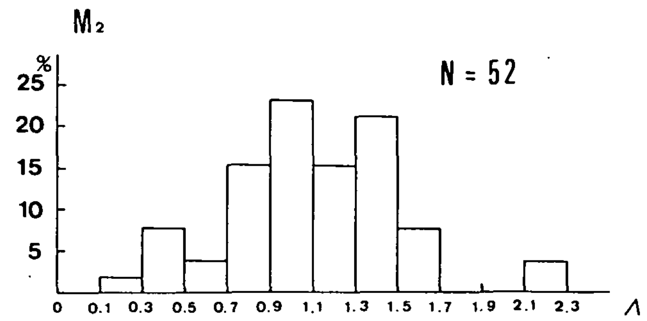

Fig. 2. Histogram of astronomically inferred values of $\Lambda = 1 + k - \ell$ factor.

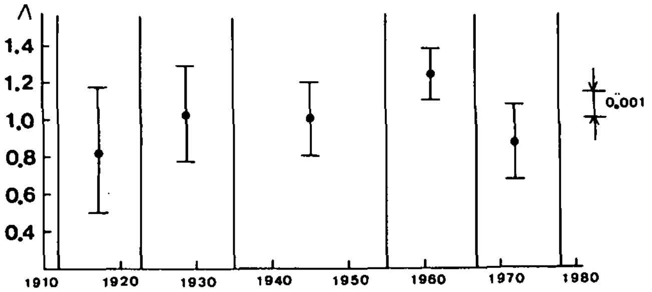

Fig. 3. Values of $\Lambda = 1 + k - \ell$ factor estimated for different periods of ILS observations.

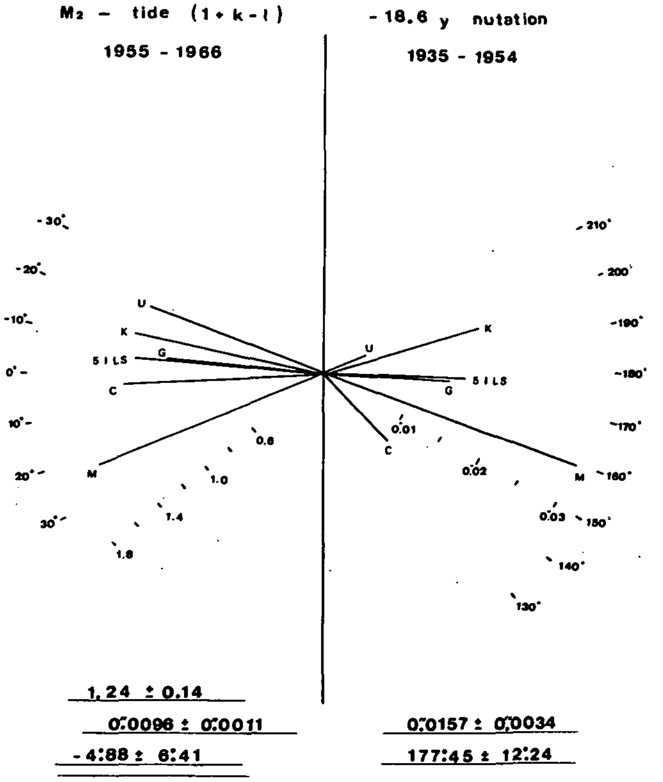
M₂ – tide (1 + k – l)
1955 - 1966
- 18.6 y nutation
1935 - 1954
-30°
-20°
-10°
0°
10°
20°
30°
U
K
5 ILS
G
C
M
0.6
1.0
1.4
1.8
210°
200°
190°
180°
170°
160°
150°
140°
130°
K
U
5 ILS
G
0.01
C
0.02
M
0.03
1.24 ± 0.14
0".0096 ± 0".0011
-4°.88 ± 6°.41
0".0157 ± 0".0034
177°.45 ± 12°.24

Fig. 4. Amplitude and phase diagram showing station-to-station differences of the estimated values of the $1 + k - \ell$ factor and retrograde component of "uncorrected" 18.6-year principal nutation. M, K, C, G, U correspond to 5 ILS stations: Mizusawa (Japan), Kitab (USSR), Carloforte (Italy), Gaithersburg (USA) and Ukiah (USA).

TABLE 2. Estimation of Love Number k from Changes in the Earth's Rotation Rate Due to M_f and M_m Tide

Theoretical Values (in msec)

M_m	$-0.77(k/0.29)\sin(L_{☾} - r')$
M_f	$-0.71(k/0.29)\sin 2L_{☾}$
...	$-0.30(k/0.29)\sin(2L_{☾} - \Omega)$

Observed k

Authors	M_f	M_m
Guinot (1970)	0.331 ± 0.061	0.265 ± 0.068
Pilinik (1970)	0.300 ± 0.005	
	$k(M_f) - k(M_m) = 0.030 \pm 0.006$	
Guinot (1974)	0.334 ± 0.005	0.295 ± 0.011
Djurovic (1975)	0.343	0.301