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A Direct Demonstration of the Lunar Barometric Tide

By B. HAURWITZ[1]) and ANN D. COWLEY[1])

Eingegangen am 13. August 1970

Summary: The three daily pressure observations at 0700, 1300, and 1800 hr. at Tananarive, Madagascar during the months May through August for the 31 years 1924 to 1954 are combined in the form

$$p(7)+p(18)-2\,p(13)$$

and plotted in 24 groups according to the lunar phase number Nu. The resulting figure (1 a) shows, despite the large scatter for each group, clearly a half-monthly wave which results from the lunar semidiurnal barometric oscillation.

Zusammenfassung: Die drei täglichen Barometerablesungen um 0700, 1300 und 1800 hr. in Tananarive, Madagaskar während der Monate Mai bis August in den 31 Jahren 1924 bis 1954 werden zusammengefaßt in dem Ausdruck

$$p(7)+p(18)-2\,p(13)$$

und für die 24 Mondphasenzahlen aufgezeichnet (Abb. 1 a). Es zeigt sich trotz der großen Streuung deutlich eine halbmonatliche Welle, welche eine Folge der halbtägigen lunaren Luftdruckschwankung ist.

Compared to the irregular barometric changes the amplitude of the lunar semidiurnal pressure variation is very small so that the analysis of a long series of data is required for its determination. Therefore it is of interest to show that one may obtain a strong indication of the existence of the lunar semidiurnal pressure oscillation merely by plotting suitably chosen data in an appropriate manner.

We have used for this purpose the pressure observations made at Tananarive (18.9°S, 47.5°E, altitude 1400 m) on Madagascar during the four months May through August (called the J season) from 1924 through 1954 at 0700, 1300, and 1800 hr. The

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three daily observations at Tananarive are combined for each day into the sum of the pressure differences,

$$s = p(7) - p(13) + p(18) - p(13).$$

Since the observations have been made at the same solar hours they fall on different lunar hours on each day of the synodic month. Therefore s should show, because of the lunar semidiurnal oscillation, a semimonthly variation if the lunar tidal effect can make itself felt above the background meteorological noise, consisting of the irregular pressure variations. Every day of each synodic month is characterized by the lunar number Nu [Chapman and Lindzen 1970], an integer measuring the phase of the moon, increasing from 0 at new moon, through 6, 12, 18 for first quarter, full moon, last quarter to 24 (or 0) at the next new moon.

Figure 1a shows for each Nu group the various values of s during the 31 J seasons at Tananarive. Although the s values for each Nu group scatter considerably one recognizes that the center of gravity of the s values for each Nu group has two maxima and two minima during the month, strongly suggesting the presence of a semidiurnal lunar oscillation in the data. A similar example of the lunar tidal variation in geomagnetic data had earlier been given by Bartels [1963].

To determine the lunar tide directly from these data one may compute the mean values $\bar{s}$ of s for each group of lunar phase numbers Nu. These means, the number n of data in each group, and the standard deviation σ of the s for each group are shown in Table 1. The units of $\bar{s}$ and σ are mm of mercury. The mean values $\bar{s}$ in this table show the semimonthly variation due to the semidiurnal lunar pressure oscillation expected in view of Figure 1a. Attention should be called to the large standard deviations for Nu equal to 6 and 7. These large values are caused by three exceptionally high values of s which are either erroneous or caused by large pressure disturbances passing over Tananarive. In either case such conspicuously high values would be

Table 1: The semimonthly lunar pressure wave

Nu	$\bar{s}$	n	σ	Nu	$\bar{s}$	n	σ
0	.84	160	.60	12	.81	160	.47
1	.87	164	.54	13	.79	155	.58
2	.82	156	.64	14	.81	155	.48
3	.89	155	.49	15	.87	162	.54
4	.95	162	.54	16	.96	154	.46
5	1.12	156	.51	17	1.04	160	.56
6	1.04	159	1.00	18	1.12	160	.55
7	1.39	159	1.52	19	1.13	156	.52
8	1.08	155	.55	20	1.06	162	.75
9	1.07	166	.55	21	1.03	155	.48
10	.94	154	.55	22	.97	164	.53
11	.82	160	.52	23	.98	157	.54

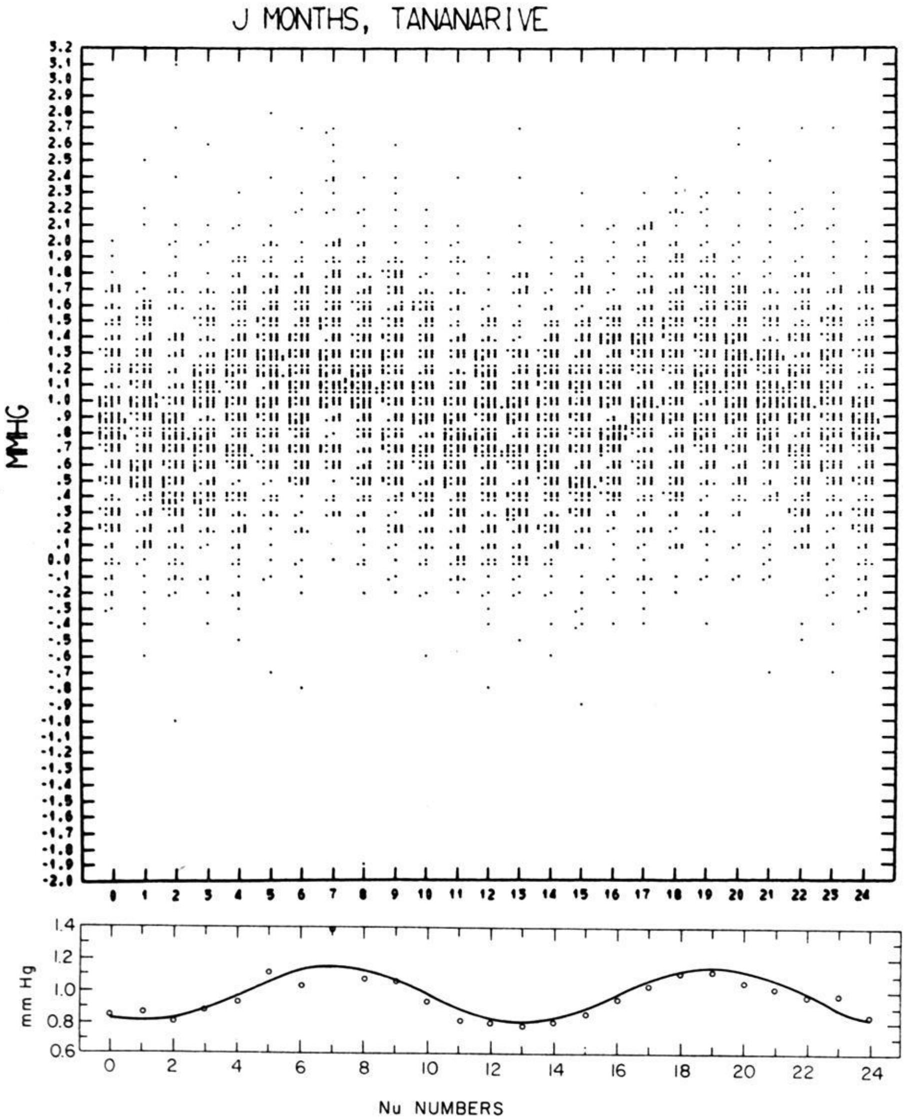

Fig. 1: The lunar barometric tide at Tananarive shown by the semimonthly variation of s (Abscissae: Nu numbers, Ordinates in mm Hg).

a) above: The points represent the individual s values for each lunar phase group.

b) below: Circles represent $\bar{s}$, the mean values of s, for each Nu group. The curve is the semimonthly period of $\bar{s}$ computed by harmonic analysis.

rejected when the lunar tide is computed. But we have purposely not omitted any data here in order to show that the lunar barometric tide can be recognized without any manipulation of the data.

The semimonthly variation of the mean pressure differences, $\bar{s}$, shown in Table 1 can be represented by

$$-\cdot 15\cos 30\nu - \cdot 09\sin 30\nu = \cdot 176\sin(30\nu + 239^\circ) \quad [\text{mm Hg}],$$

where ν is written for the lunar phase integer Nu. This semimonthly wave together with the values of $\bar{s}$ of Table 1 (circles) is plotted in Fig. 1b.

From this semimonthly variation of $\bar{s}$ the amplitude and phase constant of the lunar semidiurnal barometric tide can be estimated in the following manner. The two observations at 0700 and 1300 hr. are six (solar) hours apart, very nearly half the lunar tidal period. Therefore twice during each synodic month the pressure difference $p(7) - p(13)$, averaged for each Nu group, will be very nearly equal to the difference maximum minus minimum of the lunar semidiurnal barometric oscillation, and twice during that period it will be equal to the difference minimum minus maximum, provided that pressure variations not due to the moon's tidal force have been eliminated by the grouping and averaging, as is suggested by Fig. 1b. Thus, the second harmonic of the average difference $p(7) - p(13)$ gives approximately twice the amplitude of the lunar semidiurnal oscillation. If the other pressure difference making up s were $p(19) - p(25)$, the latter being the pressure at 0100 hr. of the next day, the same reasoning would apply as to $p(7) - p(13)$ and the semimonthly amplitude of $\bar{s}$ would be about four times the semidiurnal amplitude. Since no observations are available for these times, the pressures at 1800 hr., close to 1900 hr., and at 1300 hr., nearly a full lunar semidiurnal period before 0100 hr., had to be used. Consequently the lunar semidiurnal period is slightly larger than one fourth of the semimonthly amplitude.

To estimate the phase constant of the lunar semidiurnal oscillation we note that the maximum of $\bar{s}$ occurs approximately at Nu equal to 7 and 19. Thus $p(7) - p(13)$ and the approximately equivalent $p(18) - p(13)$ are largest shortly after the first and last quarter of the moon. Hence, say at first quarter, the pressure maximum occurs shortly after sunrise, the minimum shortly after noon. The moon at first quarter is nearly in lower transit (lunar midnight) at sunrise and six hours from upper transit (lunar noon) at solar noon. It follows that the two lunar daily tidal pressure maxima occur very nearly at the meridian passages of the moon, according to the above expression for the semimonthly variation of $\bar{s}$.

Bartels [1938] has given the exact procedure to convert the semimonthly wave into the lunar semidiurnal oscillation (see also Haurwitz, Cowley [1967]). The following expression is thus found for the lunar barometric tide

$$61\ \mu\text{b}\sin(30\tau + 91^\circ)$$

where the amplitude is now expressed in microbars, and where τ represents mean lunar time. This determination bears out the above qualitative deductions and agrees well with the more accurate one made earlier [HAURWITZ, COWLEY 1967] from much more data, namely

$$58.0\,\mu\text{b}\sin(30\,\tau + 89.4^\circ) \pm 2.4\,\mu\text{b}.$$

The present determination has certainly a probable-error circle whose radius is substantially larger than 2.4 μb so that the two results differ by less than the sum of the radii of the probable error circles.

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