V. *On the Lunar Atmospheric Tide at St. Helena.*

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Received December 16, 1846,—Read January 28, 1847.

THE attractions of the sun and moon occasion tides in the atmosphere similar to those of the ocean. The effects are, however, so inconsiderable in comparison with the disturbances produced in the equilibrium of the atmosphere by other causes, that hitherto observation has not succeeded in affording any clear or decisive evidence of them. The phenomenon however has a very considerable philosophical interest as a farther exemplification of the universality of the principle of gravitation.

As the ebb and flow of the atmospheric tide must be greatest in the vicinity of the equator, and as moreover the ordinary equilibrium is less disturbed by irregular causes in that region of the globe than in the temperate zones, it was reasonable to expect that the existence of a tide in the atmosphere, depending on the position of the sun or moon relatively to the meridian of the place, would be shown, if at all, by observations made within the tropics; and that the most favourable situation for such observations might be that of a small island surrounded by a considerable extent of ocean, and therefore comparatively free from the atmospheric disturbances occasioned by variations of the terrestrial surface; and where also the tides of the ocean should be small.

The importance of St. Helena as a station of observation for this purpose early engaged the attention of the highly intelligent director of its magnetical and meteorological observatory, Captain LEFROY of the Royal Artillery, as may be seen from the following extract of a report received from that officer, dated June 1st, 1842.

"I believe that no observations have as yet decided the question, whether any effect upon the mean barometrical pressure is produced by the moon's daily passage of the meridian. The existence of an atmospheric tide of this nature appeared however so interesting a subject of inquiry, and its detection so probable, owing to the extreme uniformity of the daily oscillation, that the observations of seventeen months, viz. from August 1840 to December 1841 inclusive, have been arranged with that view. The mode adopted was this:—the corrected height of the barometer (*i. e.* the reading reduced to 32° FAHR.) at the hour of observation nearest the moon's meridian passage for every day has been entered in a central column; and in parallel columns headed -2^h, -4^h, &c. and $+2^h$, $+4^h$, &c. have been entered the observations taken respectively at 2^h, 4^h, &c. before and after the central observation. A mean has been taken for the observations included in each lunar month. It appears from the

seventeen months thus examined, that a maximum of pressure corresponds to the moon's passage over both the inferior and superior meridians, being slightly greater in the latter case; and that a minimum corresponds nearly to the rising and setting, or to $\pm$ 6^h. The average of the seventeen months gives the respective pressures as follows, viz.—

	in.
Moon on the meridian	28·2714
Moon in the horizon	28·2675

The difference being ·0039 in.

"The latitude of the observatory is —15° 57′; the height above the sea, ascertained by levelling, 1764 feet to the cistern of the barometer. Observations made in 1827 under the direction of Major-General Walker, gave the particulars of the oceanic tides as follows:—

Rise at new moon . .	3 feet 6 in.
Rise at full moon . . .	2 feet 9½ in.
Rise at the quarters . .	1 foot 5 in.
Establishment	2^h, 20^m.

"There appears to be no establishment in the atmospheric tide, consequently the rise in the ocean will not account for the variation in the height of the barometer, because the times of maximum do not coincide."

Early in 1842 Captain Lefroy was succeeded in the charge of the observatory at St. Helena by Captain Smythe of the Royal Artillery; and from the 1st of October of that year, the observations, which up to that period had been taken at every second hour of mean solar time, were taken at every hour, and thus in their re-arrangement in lunar time, the mean height of the barometer at the different lunar hours became better represented than had been the case under the two-hourly system. During the first year of the hourly observations, viz. from October 1842 to September 1843 inclusive, the examination of the moon's influence continued to be carried on at the observatory by Captain Smythe in a somewhat modified manner, which is thus described by him:—"The hourly observations for each day, extracted from the day-book, were grouped into lunar months, and the monthly mean for each hour found. The observation taken each day at the hour nearest the time of the moon's meridian transit was inserted in the centre column for that day, and the other observations disposed right and left in order. As however the observations in this state are affected by the diurnal variation, which at St. Helena is very regular and considerable, and by which the moon's effect would have been overridden, the monthly mean for the hour was subtracted from each observation taken at that hour, and the remainder regarded as due to the moon's action. When only twenty-three observations intervened between two meridian transits of the moon, the middle observation was entered in both the —12 and +12 column."

Variation of the Barometer at the several Lunar Hours, from October 1842 to September 1843 inclusive, in decimals of an inch, + signifying an excess of barometric pressure, and — a defect.

1st. From the superior to the inferior passage.

Moon on the upper meridian.	+1h.	+2h.	+3h.	+4h.	+5h.	+6h.	+7h.	+8h.	+9h.	+10h.	+11h.	+12h.
+·0014	+·0011	+·0002	·0000	−·0008	−·0010	−·0012	−·0018	−·0011	−·0005	+·0002	+·0012	+·0012

2nd. From the inferior to the superior passage.

−12h.	−11h.	−10h.	−9h.	−8h.	−7h.	−6h.	−5h.	−4h.	−3h.	−2h.	−1h.	Moon on the upper meridian.
+·0016	+·0012	+·0009	+·0002	−·0006	−·0010	−·0011	−·0010	−·0004	+·0004	+·0003	+·0016	+·0014

We have here an average excess of barometric pressure of ·0014 in. at the hour when the moon is on the meridian above or below the pole, and an average defect of ·00115 at the period when she is six hours distant from the meridian; making together an average difference in the height of the barometer of ·00255 in. between the hours when the moon is on the meridian and when she is six hours distant from it.

The arrangement of the observations for the investigation proving rather a heavy charge on the establishment at St. Helena, the examination was now taken up at Woolwich, and carried through a subsequent period of two years, *i. e.* from October 1843 to September 1845 inclusive, for which the following method was adopted:—

If we call b the height of the barometer at 32° at any hour of observation, and $\overline{b}$ the mean height of the barometer at the same hour during the month to which the day belongs, then $b-\overline{b}$ is a quantity which remains over after the approximate diurnal variation has been eliminated; it is + when the barometer is higher and − when it is lower than the normal state, and expresses by how much the barometer is higher or lower at that observation than the normal state at the same hour. Monthly tables are then formed in which are inserted the values of $b-\overline{b}$ for each hour of mean solar time. The mean solar hours which are respectively nearest to the several lunar hours are then computed for every day, and the values of $b-\overline{b}$ are re-arranged in lunar monthly tables. The means at the several lunar hours in each month are then taken; and these means are finally arranged in periods of six months, yielding mean values of the barometrical variation at the several lunar hours for each half year. These are shown in the following tables:—

1st. From the superior to the inferior passage.

	Lunar hours.											
	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Oct. 1843 to March 1844 ...	+·0017	+·0012	+·0004	−·0007	−·0021	−·0018	−·0018	−·0016	−·0019	−·0013	−·0004	+·0014
April 1844 to Sept. 1844 ...	+·0023	+·0020	+·0015	+·0007	−·0001	−·0013	−·0028	−·0027	−·0011	−·0004	−·0006	+·0009
Oct. 1844 to March 1845 ...	+·0021	+·0026	+·0023	+·0014	+·0007	+·0001	−·0007	−·0003	+·0005	+·0010	+·0017	+·0006
April 1845 to Sept. 1845 ...	+·0009	+·0001	−·0008	−·0018	−·0021	−·0024	−·0032	−·0024	−·0008	+·0008	+·0016	+·0026
Mean of the 1st year.....	+·0020	+·0016	+·0009	·0000	−·0011	−·0016	−·0023	−·0022	−·0015	−·0009	−·0005	+·0012
Mean of the 2nd year	+·0015	+·0014	+·0008	−·0002	−·0007	−·0012	−·0020	−·0014	−·0002	+·0019	+·0016	+·0016
Mean of the four half years	+·00175	+·00148	+·00085	−·00010	−·00090	−·00135	−·00212	−·00175	−·00082	+·00002	+·00058	+·00138

2nd. From the inferior to the superior passage.

	Lunar hours.											
	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.
Oct. 1843 to March 1844 ...	+·0021	+·0020	+·0015	−·0006	−·0002	−·0005	−·0008	−·0007	+·0003	+·0012	+·0016	+·0018
April 1844 to Sept. 1844 ...	+·0005	−·0002	−·0007	−·0009	−·0015	−·0014	−·0015	−·0005	+·0003	+·0018	+·0024	+·0027
Oct. 1844 to March 1845 ...	+·0011	+·0007	−·0004	−·0024	−·0024	−·0026	−·0026	−·0023	−·0018	+·0001	·0000	+·0005
April 1845 to Sept. 1845 ...	+·0027	+·0022	+·0018	+·0010	−·0006	−·0015	−·0024	−·0023	−·0021	−·0001	+·0006	+·0012
Mean of the 1st year.....	+·0013	+·0009	+·0004	−·0008	−·0009	−·0010	−·0012	−·0006	+·0003	+·0015	+·0020	+·0023
Mean of the 2nd year	+·0019	+·0015	+·0007	−·0007	−·0015	−·0021	−·0025	−·0023	−·0020	·0000	+·0003	+·0009
Mean of the four half years	+·00160	+·00118	+·00055	−·00072	−·00118	−·00150	−·00182	−·00145	−·00082	−·00075	+·00115	+·00155

The evidence is here of the most decisive character of a barometrical maximum at the lunar hours of 0 and 12, and a minimum at 6 and 18, with a corresponding progression at the intermediate hours.

If we now arrange these results in such manner that the hours are combined in which the moon is similarly situated in respect to the meridian, we have the lunar horary variation of the barometer as follows :—

Moon's distance from the meridian.	Variations of barometric pressure.			Horary variation.			Moon's distance from the meridian.
	At the hours following the meridian passage.		At the hours preceding the meridian passage.		From the observations at the hours following the meridian passage.	From the observations at the hours preceding the meridian passage.	Mean.	
h	h in.	in.	h in.	in.	in.	in.	in.	h
0	0 +·00175 12 +·00160	+·00168	0 +·00175 12 +·00160	+·00168	+·00365	+·00365	+·00365	0
1	1 +·00148 13 +·00118	+·00133	11 +·00138 23 +·00155	+·00146	+·00330	+·00343	+·00336	1
2	2 +·00085 14 +·00055	+·00070	10 +·00058 22 +·00115	+·00086	+·00267	+·00283	+·00275	2
3	3 −·00010 15 −·00072	−·00041	9 +·00002 21 −·00075	−·00036	+·00156	+·00161	+·00158	3
4	4 −·00090 16 −·00118	−·00104	8 −·00058 20 −·00082	−·00070	+·00093	+·00127	+·00110	4
5	5 −·00135 17 −·00150	−·00142	7 −·00175 19 −·00145	−·00160	+·00055	+·00037	+·00046	5
6	6 −·00212 18 −·00182	−·00197	6 −·00212 18 −·00182	−·00197	00000	00000	00000	6

It should here be remarked, that as the observations were made at hours of solar time, they could not of course strictly correspond in the majority of cases to the lunar hours under which the value of $b-\bar{b}$ have been arranged. The effects of this imperfect synchronism have a tendency to compensate each other, and are probably nearly compensated, at all the lunar hours except at 0 and 12, 6 and 18. These, however, are the most important hours for the determination of the maximum effect, and, supposing there to be no establishment, it is obvious that whether the observation precedes, or whether it follows the precise lunar hour to which it should correspond, the error produced will be the same in kind, viz. the maximum at 0^h and 12^h will be lowered, and the minimum at 6^h and 18^h will be raised; and in both cases the error will tend to diminish the apparent influence of the moon's position on the barometric pressure. It may therefore be presumed that the true horary variation corresponding to the lunar hours is in every case greater than the numbers which appear in the preceding table; and that the horary variation at 0^h and 12^h which should express the whole difference of pressure corresponding to the moon's positions on the meridian and at six hours' distance from it, is especially less than the true amount, being diminished by the causes above mentioned, both at the hours when the moon is on the meridian and when she is six hours distant. To obviate this inconvenience and to give the results in future as much precision as they are capable of, eight additional observations, at equal lunar intervals, will hereafter be made in each day, corresponding precisely to the lunar hours of 0, 3, 6, 9 . . . . . 21; and these observations will be made on Sundays as well as on other days.

We may conclude therefore as the result of the two years of observation from October 1843 to September 1845 inclusive, that the barometer at the Observatory at St. Helena is higher when the moon is on the meridian, either above or below the pole, than when she is six hours distant from the meridian, by an average quantity which exceeds ·00365 in., and may be taken in round numbers as ·004 in.

For the purpose of examining whether any perceptible difference in the influence of the moon on the barometric pressure could be detected at the periods of the apogee and perigee, the following method was adopted. The epoch of the moon's perigee or apogee being taken from the Nautical Almanac, the nearest of the lunar hours 0, 6, 12, or 18 to that epoch is taken as the middle term of comparison; if it be 0 or 12 hours, the values of $b-\bar{b}$ at the four antecedent and four subsequent lunar meridian hours (0 and 12) are taken in addition to the middle term, to give a mean value corresponding to the times when the moon is on the meridian above or below the pole. The mean of the eight intermediate values of $b-\bar{b}$ at 6 and 18 hours taken in like manner, furnishes a mean value corresponding to the times when the moon is six hours distant from the meridian. The difference between these mean values of $b-\bar{b}$ gives for the epoch in question, the excess of the barometrical pressure when the moon is on the meridian above the pressure when she is six hours distant from it. Theoretically, this excess should be greater at periods of perigee than at those of apogee.

If the lunar hour nearest to the epoch of apogee or perigee be 6 or 18 instead of 0 or 12, that hour is taken as the middle term of comparison, and the mean values of $b-\bar{b}$ consist in such case of the mean of nine values at 6 and 18 hours, and of eight at 0 and 12. When a Sunday intervenes the same number of values of $b-\bar{b}$, viz. eight of the one and nine of the other, are taken to give the mean value in the comparison, which consequently in such case extends to a somewhat greater distance on either side of the middle term than when no such interruption occurs.

The mean excess of barometrical pressure when the moon is on the meridian, resulting from this comparison, is as follows :—

From 13 epochs of perigee between October 1843 and September 1844	·00407 in.
From 13 epochs of perigee between October 1844 and September 1845	·00394 in.
From 13 epochs of apogee between October 1843 and September 1844	·00341 in.
From 14 epochs of apogee between October 1844 and September 1845	·00347 in.

The number of observations from which each of the first three results is obtained is 221 ; in the fourth case it is 238.

We have here in both years a consistent indication of the greater influence of the moon on the barometrical pressure at periods of perigee than at those of apogee.

The effect of the solar action on the atmospheric pressure is far more difficult to be shown by any mode of grouping the observations than is that of the moon, not only because it is much smaller, but because it is masked in the diurnal barometric oscillation by the much greater and variable influence of the solar heat in producing atmospheric variations. That it is eliminated, in common with the other variations which depend on the sun's horary angle, by the process described in this paper, may be inferred from the fact that no significant difference appears in comparing the excess in the values of $b-\bar{b}$ at the lunar hours of 0 and 12, at the periods of syzygies and quadratures, during the twelve months from October 1843 to September 1844 inclusive. The mean values in this comparison have been taken from the observations at 0^h and 12, 6 and 18 for 36 hours preceding, and 36 hours following, the epoch of each syzygy and quadrature. The mean excess at 0 and 12 at the periods of syzygy is ·00337, and at those of quadrature ·00345.

The quantities treated of in this communication will justly appear to many persons as extremely small; but the consistency of the partial results, when the observations are broken into periods of six months, places beyond doubt the power of observation, in appropriate circumstances and continued for a sufficient time, to determine both the existence and the approximate amount of a diurnal systematic affection of the barometer, not exceeding four thousandths of an inch. It also affords an instructive example of the beneficial influence of *mean numerical values* in the advancement of the physical sciences, and of the power which we possess through their means of progressively separating from apparently irregular phenomena, that which is constant and reducible to laws.