LUNI-SOLAR VARIATIONS IN THE IONOSPHERE

By R. A. Duncan*

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Summary

Martyn's luni-solar analyses of $h^{\max.}F_2$ and f_0F_2 at Huancayo and Canberra, are restudied; not all the coefficients are found to be significant. The E region near the magnetic equator appears to fail abruptly as a dynamo at sunset; that above Canberra remains active until midnight.

I. Introduction

It is well known that the electron densities and heights of the ionospheric layers vary slightly with lunar time (Appleton and Weekes 1939; Martyn 1947; Burkard 1948). Meaned over a month or more, these variations are predominantly semi-diurnal, as is to be expected, because a semi-diurnal lunar variation of barometric pressure is found at the ground, and the ionospheric variations must be caused, ultimately, by a similar gravitational tide in the upper atmosphere.

The ionospheric effect of the lunar tidal motion, however, even the direction of the effect, depends on the morphology of the ionosphere, a thing chiefly under solar control. This may greatly complicate the actual lunar variation on a given day.

Martyn (1947, 1948) attacked this problem by studying the variation with lunar time of f_0F_2 and $h^{\max.}F_2$ measured at chosen solar hours each day. Chapman and Bartels (1940) have shown that such studies need interpretation.

In this paper we examine Martyn's Huancayo and Canberra $h^{\max.}F_2$ and f_0F_2, luni-solar coefficients, and find that not all of them are significant. We interpret the significant variations in terms of Martyn's lunar tidal theory (Martyn 1947; Duncan 1956), that is, in terms of electric currents in the E region setting up polarization which is conducted along the geomagnetic field lines to the F region.

II. General Considerations

A "semi-diurnal" lunar coefficient determined from observations at a fixed solar hour each day, does not necessarily reflect semi-diurnal behaviour, that is, a variation of the form cos $2l$, where l is the lunar hour angle. It can be caused by any variation of the form $\cos 2(l-ns)$, where s is the solar hour angle and n an integer. If, however, the lunar coefficient is determined for each solar hour, and the lunar phase is plotted against solar hour, the ambiguity is resolved. If the slope of the phase plot is μ, the variation can be formally described by a function of the form $\cos 2(l-\mu s)$.

* Upper Atmosphere Section, CSIRO, Camden, N.S.W.

However, because of the conservation of geophysical data, the lunar phase determinations for each solar hour are not necessarily independent; a non-significant long period variation will similarly influence them all. With semi-diurnal luni-solar coefficients it is a non-significant semi-monthly variation which matters. This, having the form cos $2(l-s)$ [$(l-s)$ is the lunar phase] produces an upward-sloping phase plot. In such a plot it is necessary to test the significance of each point separately; we have applied the criterion that the semi-diurnal component must account for at least half of the total variance.

On the other hand, a horizontal phase plot, cos $2l$, indicates a true lunar semi-diurnal variation. This cannot be caused by conservation; in this case each point corroborates the evidence of its neighbours.

If we look, not for a semi-diurnal, but for a lunar semi-monthly variation, the situation is reversed. Now it is a semi-monthly variation which has a horizontal, and a semi-diurnal lunar variation which has a sloping, phase plot with solar hour. Neglect of this consideration caused an apparent disagreement between the results of Martyn (1947) and those of McNish and Gautier (1949).

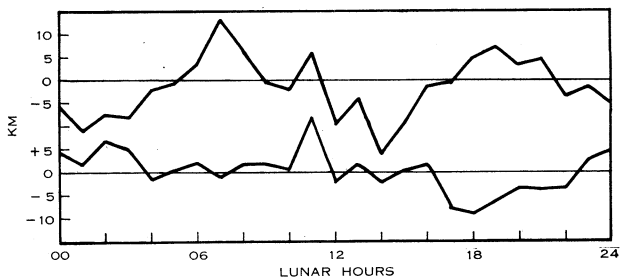

Fig. 1.—The lunar variations of the daily values of Huancayo $h^{\max.}F_2$ at 13 and 01 solar hours respectively; 1942–43–44.

III. Analysis

(a) $h^{max.}F_2$ *Huancayo*

The mean (1942–43–44) lunar variations of $h^{\max.}F_2$ Huancayo at 01 and 13 solar hours are shown in Figure 1. Only the 13 solar hour plot shows a lunar effect. Computation shows that none of Martyn's night-time luni-solar coefficients are significant (Fig. 2), but all those between 07 and 18 solar hours account for well over 50% of the total variance. Furthermore, this part of the phase plot (Fig. 2) is substantially horizontal, so that the day-time variation is semi-diurnal in the true sense of the word. But the variation ceases abruptly at sunset, and this must mean that near the magnetic equator the *E* region ceases to support a lunar current system at sunset.

(b) f_0F_2 *Huancayo*

Luni-solar studies of critical frequency at Huancayo confirm this conclusion. Again midday critical frequencies show a large lunar effect, midnight critical frequencies show none (Fig. 3), and after applying a significance test, we have rejected some of the points in Martyn's phase plot (Fig. 4).

The horizontal part of the phase plot, i.e. between 08 and 17 solar hours, indicates the presence of a simple semi-diurnal tide during the day.

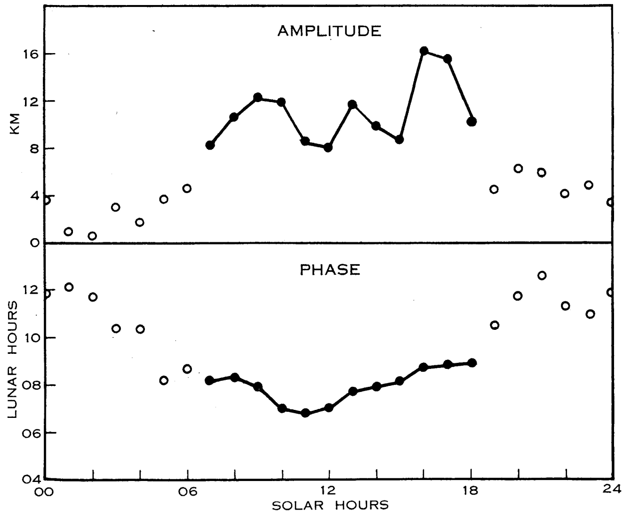

Fig. 2.—The solar hour variation of the semi-diurnal luni-solar coefficients for Huancayo $h^{\max.}F_2$; 1942–43–44. Non-significant points are shown as open circles.

Between 17 and 21 solar hours the phase plot slopes upward at about 1 lunar hour per solar hour, that is, we have a variation of the form cos $2(l-s)$, a semi-monthly variation. This implies the following behaviour. Active lunar perturbation of the

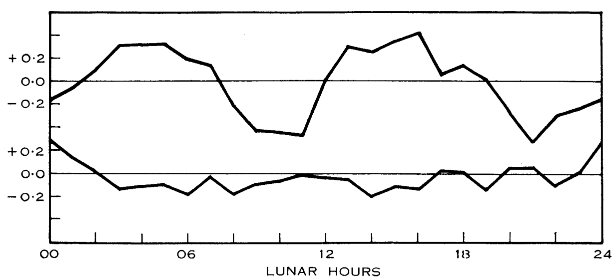

Fig. 3.—The lunar variations of the daily values of Huancayo f_0F_2 at 11 and 23 solar hours respectively; 1942–43–44.

F_2 at Huancayo ceases at sunset, but the electron density tends to retain, until 21 solar hours, the perturbation with which it was left at sunset. The critical frequency between 18 and 21 solar hours depends, then, on the lunar hour at sunset, that is, on the lunar age.

There is, as we have said, no evidence of any lunar control of the critical frequency during the middle of the night; the general upward slope is caused by conservation, but at 04 and 05 solar hours significant lunar control appears again, but with a phase, 10 lunar hours, opposite to that observed during the day. This is to be expected. During the day upward lunar drift increases the electron density by lifting electrons to a region of low decay. In the brief dawn period a downward lunar drift favours increased ion density, as it causes the ions to follow the downward dawn movement of the height of maximum ion production.

Luni-solar studies of Huancayo f_0F_2, then, confirm the conclusion reached from the study of $h^{\text{max.}}F_2$. Lunar electric currents and polarization are significant only during the day.

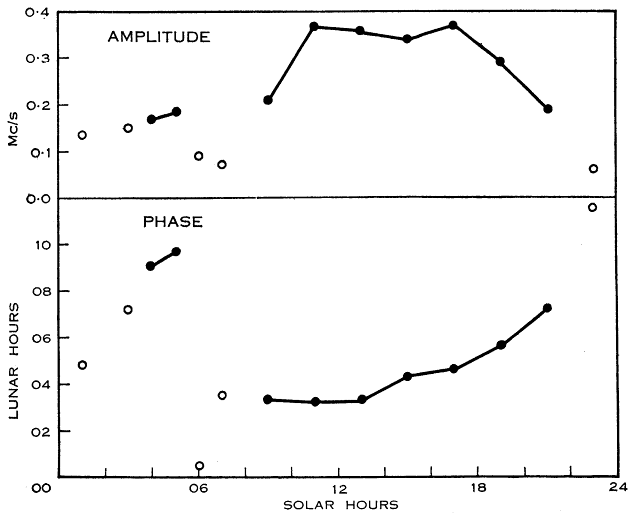

Fig. 4.—The solar hour variation of the semi-diurnal luni-solar coefficients for Huancayo f_0F_2; 1942–43–44. Non-significant points are shown as open circles.

(c) *Canberra* $h^{max.}F_2$

Martyn's luni-solar coefficients for Canberra $h^{\text{max.}}F_2$, 1942–43–44, are shown in Figure 5. The coefficients for solar hours 17 to 23 account for from 25% to 55% of the variance at these hours, and, as they have similar phases, they may be accepted as genuine.

The coefficients for other times of the day are not significant, but the amplitudes at these hours are not small. Hence masking by increased random fluctuations, rather than lessening of the lunar effect could be the explanation.

(d) *Canberra* f_0F_2

The ratio of regular to random variation at Canberra is much smaller than at Huancayo, and only two of Martyn's luni-solar coefficients for Canberra f_0F_2, the ones for 06 and 14 solar hours, account for more than half of the total variance (Fig. 6). However, there are reasons for considering some of the other coefficients genuine.

The coefficients between 14 and 23 hours have very similar phases, and, although they account, on the average, for only about 40% of the total variance, they can only be due to a genuine semi-diurnal lunar variation.

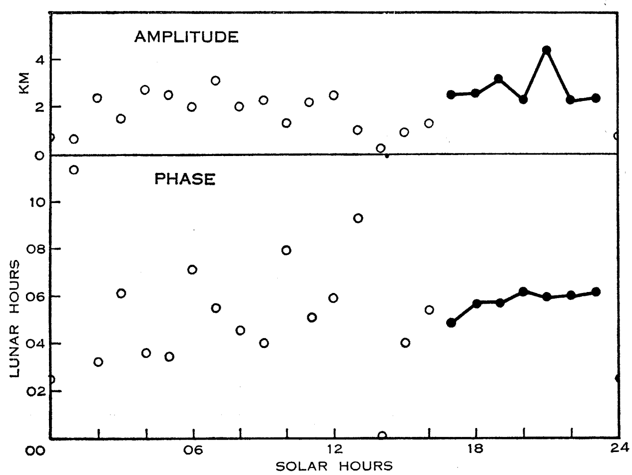

Fig. 5.—The solar hour variation of the semi-diurnal luni-solar coefficients for Canberra $h^{\text{max.}}F_2$; 1942–43–44. Non-significant points are shown as open circles.

The coefficients between 07 and 13 solar hours have small amplitudes and scattered phases; five of them account for less than 10%, and the remaining two

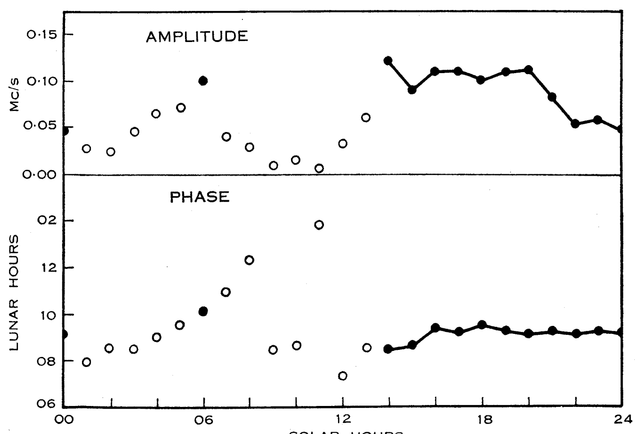

Fig. 6.—The solar hour variation of the semi-diurnal luni-solar coefficients for Canberra f_0F_2; 1942–43–44. Non-significant points are shown as open circles.

(07 and 13 solar hours) account for less than 20% of the total variance at each solar hour. There is therefore no evidence of lunar tidal effects during the early and middle part of the day. This is not likely to result from failure of E-region conduc-

tivity; it is almost certainly a consequence of the short relaxation time of the F region during this period of rapid electron production and decay.

The phase progression of the coefficients between 00 and 05 solar hours suggest mere conservation, but the coefficient for 06 solar hours accounts for 60% of the variance at this hour and must be accepted. At Huancayo the dawn luni-solar coefficient had a phase opposite to those during the day; at Canberra, at a middle latitude, the dawn and day-time phases are similar. This is because at non-equatorial latitudes ionization diffuses down the field lines under gravity and is ultimately lost at low heights by rapid decay. At any solar hour upward drift mitigates this process and enhances the electron density; a downward drift never increases the electron density, the electrons diffuse down—too rapidly for their own long-life—without the help of drift.

IV. Conclusions

Studies of both $h^{\max.}F_2$ and f_0F_2 at Huancayo suggest that the part of the E region magnetically linked to the equatorial F region, that is, the E region at magnetic latitudes $\pm 10°$, fails as a lunar tidal dynamo at sunset. The E region above the middle-latitude station, Canberra, appears to act as a tidal dynamo until midnight.

V. References

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