where the time dependence of magnetic, electric and electric polarization fields is specified by:

$$\boldsymbol{B} = \boldsymbol{B}_0 e^{\alpha t}, \ \boldsymbol{E} = \boldsymbol{E}_0 e^{\alpha t}, \ \boldsymbol{P} = \boldsymbol{P}_0 e^{\alpha t}$$

The equation, together with the boundary conditions, can be considered in terms of poloidal and toroidal representations of the vector fields. When the conductivity (σ) depends upon the radius only, the inducing poloidal magnetic variation gives rise to a purely poloidal magnetic field in the conducting sphere; the inducing and induced fields are associated with toroidal current systems. However, when σ is not uniform over a spherical surface, then the induction equation for $\boldsymbol{B}$ includes a toroidal component of $\nabla\sigma \times \boldsymbol{E}_0$, which will be balanced by the toroidal form of $\alpha\nabla \times \boldsymbol{P}_0$ associated with a poloidal polarization electric field.

The special functions $j_n(\sqrt{ikr})$ required to represent the radial dependence on the induced fields can be set down exactly in terms of trigonometric and exponential functions. Real and imaginary parts of the ratios j_n/j_{n-1} for $n = 1,2,3,4$, can also be set down exactly. These expressions will be compared with the power series and asymptotic series used by Chapman-Whitehead and Lahiri-Price.

Attention is drawn to the use of equator-symmetric seasonal variation terms in induction studies, and also to the mathematical form of magnetic disturbance used by Chapman and Whitehead, as a means of providing further electromagnetic response functions for modelling the electrical conductivity of the earth.

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Solar and lunar magnetic tides at midnight

R. J. Stening

School of Physics, The University of New South Wales, Kensington, NSW 2033, Australia.

Solar tides

The method of Winch (1981) is used to extract the annual and semi-annual components in the magnetic elements starting with hourly values. A series of coefficients of the form:

$$A_{kn}\sin(nt + kh + \lambda_{kn})$$

are obtained for $n = 1$ to 4 and $k = -2$ to $+2$. Here t is the local time and h is the longitude of the mean sun (giving variation with season). These 20 coefficients can then be used to reconstitute the daily variation curve for any season h. This study investigates the variation of the midnight ($t = 0$) values with season.

The data used to derive the coefficients are hourly values for 1964 and 1965 with the five disturbed days of each month omitted. At sunspot minimum this will correspond to relatively quiet conditions.

In Fig. 1 the variation with season of the midnight values of the horizontal component of the magnetic field H is plotted for selected stations. The main point to notice is the large enhancement of this variation at the dip equator (equatorial electrojet stations). The variation at Huancayo is more than 3 times that at Tatuoca or Fuquene, and that at Trivandrum is more than 2.5 times that at Alibag. Addis Ababa also shows a large variation.

The form of the variation, with maxima at solstices and minima at equinoxes, is similar to that obtained by Campbell (1981). But the analysis of Campbell does not yield the large enhancement at the dip equator. He finds a more gradual decrease in amplitude of this variation with latitude, and so is able to explain it in terms of the latitudinal movement of a ring current on the tail side of the magnetosphere at a distance of about two earth's radii ($2r_e$).

While this mechanism may be responsible for some of the observed semi-annual variations at midnight, the dip equator enhancement suggests that there must also be a contribution from a westward equatorial electrojet. Note also that, as the dayside electrojet is stronger at Huancayo than at Trivandrum, so also it appears the night electrojet is similarly stronger (a seasonal change of 15.0 nT at Huancayo and 8.9 nT at Trivandrum).

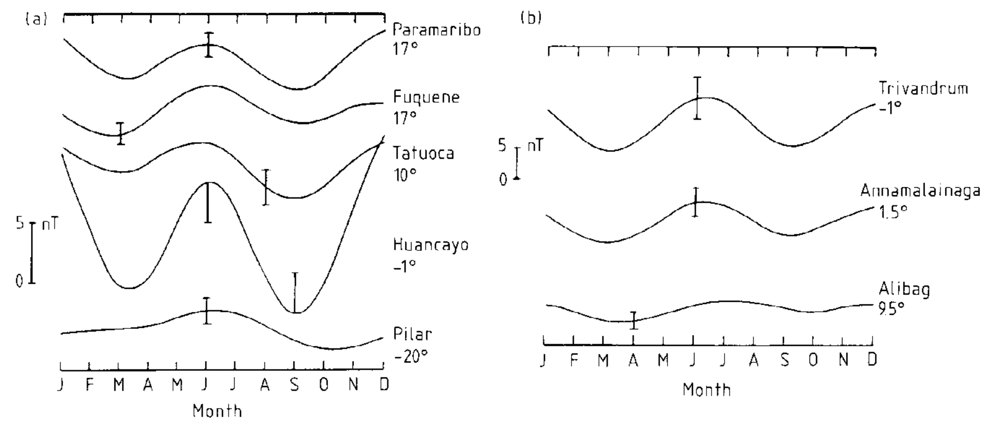

Fig 1 Midnight values of the solar variation of H in (a) the American sector and (b) the Indian sector.

The suggestion of a night-time electrojet of this magnitude poses problems. The night-time conductivity in the E-region is generally considered to be only about 1/40 of the daytime value. Furthermore at sunspot minimum the results of Fejer *et al.* (1979) indicate that F-region vertical drifts (and so electric fields) are also smaller at night than during the day (though the reverse appears to be true at sunspot maximum). This effect is discussed by Stening (1981). Thus if the daytime electrojet yields 100 nT for ΔH on the ground (a typical value for 1964–65), then the night-time jet should only give about 2 nT which is far short of that indicated by the results presented here. Some of the deficit will be made up from currents flowing in the F-region (Rishbeth 1981) but it is not clear how much.

Solar tide in Z

The season variations in the vertical component Z of the geomagnetic field are shown in Fig. 2. The form of the variations is again similar to that obtained by Campbell (1981) but in this case the amplitudes are smaller; for example, at Huancayo Campbell finds a difference of 8.5 nT between June and December while the largest change found in this study is 5.7 $\pm$0.9 nT with a maximum in August. At 10° Campbell finds 12.8 nT and in this study only 4.7 $\pm$1.3 nT at Tatuoca. Campbell uses a much smaller data set with only 37 of the quietest days in 1965 selected. By contrast this analysis at Huancayo includes 592 days for H and 299 days for Z. It is hard to understand how this analysis, which includes 'less quiet' days, gives a smaller seasonal variation than that of Campbell, especially if the movement of the ring current position is responsible.

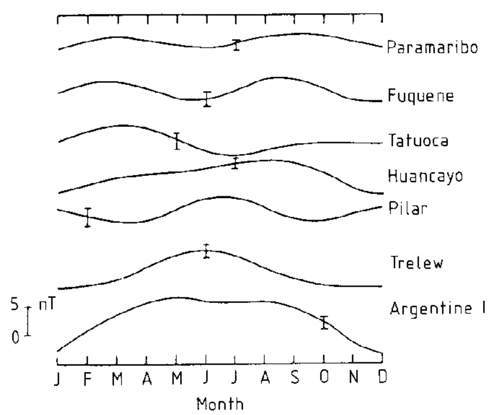

Fig 2 Midnight values of solar variation of Z in the South American sector.

Lunar variations

The midnight value of the lunar geomagnetic variation has been used by Malin (1970) to deduce the 'oceanic component' on the assumption that ionospheric contributions will be negligible at midnight. Schlapp (1977) has shown that there are appreciable seasonal variations in the midnight lunar magnetic variation of Z at Honolulu very similar to that shown in Fig. 3. Schlapp uses 37 years of data so that all points are statistically significant. This result may be interpreted as either: a constant M_2 tide plus an O_1 component; or a seasonally varying M_2 tide. Schlapp adopts the former explanation because the phase progression is that of a diurnal tide.

If this variation is of oceanic origin, it implies that the O_1 component of the ocean-generated geomagnetic tide has a similar magnitude to the M_2 component. But observations show that the O_1 component is only about 3% of the M_2 component of the tide in ocean heights. Seasonal variations of ocean tides are also small (2–3%). It therefore seems unlikely that the seasonally varying part of this geomagnetic tide is of oceanic origin. Other examples of lunar midnight tides varying with season are also shown in Fig. 3. The Watheroo results use coefficients taken from a study by Winch and Cunningham (1972) which utilized 40 years of data, while other stations used only 2 years of data (1964–65). One can find other results similar to Honolulu (as Kakioka Z) while others show a variation of amplitude only with season (Simosato Z) or virtually no variation (Watheroo Z).

An understanding of these lunar midnight tides must await an even more comprehensive analysis.

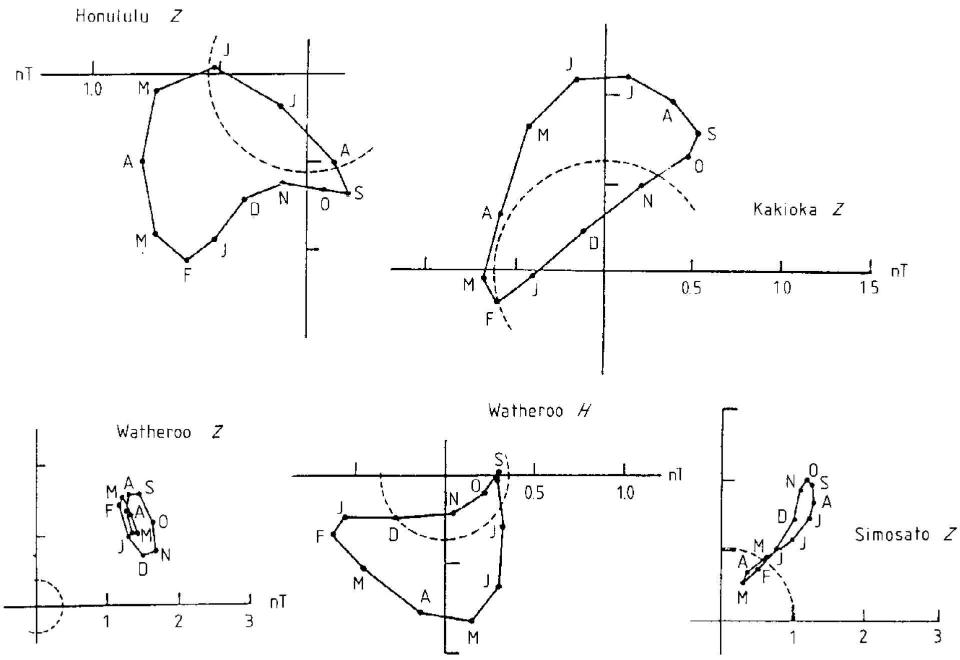

Fig 3 Phase and amplitude variation with season of lunar midnight values at various stations.

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Annual, semi-annual and solar cycle variations in Sq, and ring current effects

F. H. Hibberd

Physics Department, University of New England, Armidale, NSW 2351, Australia.

The difference of *H* at two magnetic observatories on the same meridian, but having latitudes equatorwards and polewards of the latitude of the Sq focus, yields a measure of Sq intensity largely free from disturbance. This is because the Sq variations are of opposite sign at the two observatories whereas the disturbance variations, having the same sign and roughly equal magnitudes, almost cancel each other in the difference. As a consequence, data from all days may be used to study Sq, rather than from quiet days alone, and this results in improved time resolution so that Sq is easily examined from month to month and the seasonal variation of Sq is clearly delineated.

Data from pairs of observatories in both the northern and southern hemispheres have been examined and it is found that as well as an annual variation of the range of Sq, with a maximum in local summer and a minimum in local winter,