Night-time lunar geomagnetic tides at stations far from the ocean

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Summary. If sufficient data are taken, the lunar tide at midnight at certain stations a very great distance from the coast, such as Irkutsk (Siberia), is found to be significantly different from zero. This provides further evidence for the existence of a non-oceanic contribution to the night-time lunar geomagnetic tide.

1 Introduction

It has been realized for some time that geomagnetic lunar variations may be due not only to ionospheric dynamo currents but also to dynamo action in the ocean and even possibly in the solid Earth. The problem of separating the ionospheric and oceanic contributions to the geomagnetic lunar variations has been reviewed by Malin (1977) who also gave an account of early work on the subject.

Malin (1970) devised a method for separating the parts of ionospheric and oceanic origin, based on the assumptions that the oceanic conductivity shows no dependence on time, and that the ionospheric conductivity at the height where the dynamo currents flow drops at night to a small fraction of its daytime value, so that the ionospheric contribution to the geomagnetic lunar tide at midnight could be taken to be zero. Malin proposed that the lunar tide at midnight could thus be taken to be due purely to the ocean dynamo and derived an expression for the oceanic contribution in terms of the four standard harmonic terms given by the Chapman-Miller method of lunar analysis. He tested his method by applying it to 18 months of data from Irkutsk, an observatory which is at a very great distance from the ocean and found that, as expected, the lunar tide at midnight in declination did not differ significantly from zero.

It was pointed out by Schlapp & Weekes (1973) that since the Chapman-Miller method uses only four harmonics, it is only able to give an approximate representation of the variation of lunar tides with solar time, and that, in particular at midnight when the total lunar tide is small, the fractional error in it may be proportionately large. Thus the determination of ocean dynamo contributions using Chapman-Miller harmonics is likely to be subject to considerable uncertainty. Schlapp & Weekes proposed an alternative method of

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lunar analysis of the fixed solar hour type, intended to avoid this problem. The method is based on the assumption that the lunar tide is constant for a few hours round local midnight, as it would be if it were due only to the oceanic dynamo.

If the fixed solar hour method is used to analyse the geomagnetic tide at midnight for observatories for which long series of data are available, it is found that there are significant variations of the midnight tide with season and magnetic activity (Schlapp 1977). Since the ocean tides have negligible seasonal variations and it seems highly improbable that they would show variations with magnetic activity, the results seem to indicate that the lunar tide at midnight cannot be due to an oceanic component alone, but must contain a significant contribution from sources in the atmosphere. If, however, there is a non-oceanic contribution to the tide at local midnight, it is possible that the tide is not constant for the few hours around midnight, and if so, the assumption upon which the fixed solar hour method is based would not be valid. Although tests during the development of this method showed no obvious lack of constancy in the tide around midnight, some types of systematic change in the tide would be hard to detect. There may therefore also be some uncertainty in the determination of tides at midnight by the fixed solar hour method.

If the tide at midnight does indeed contain a non-oceanic contribution, it might be expected to be detectable at stations far from the coast. Some light may therefore be thrown on the problem by studying longer runs of data from such stations.

2 Data and analysis

Data from the magnetic observatories at Irkutsk, Siberia, and Boulder, Colorado, were chosen for this study; the coordinates and time span of the data for each station are given in Table 1. The long series of data for Irkutsk has only recently become available and was supplied in machine-readable form by the World Digital Data Centre (WDDC) B2 in Moscow. In 1959 the Irkutsk observatory changed site from Zuy to Patrony, but since the observatory lies some 2000 km from the nearest ocean and the separation of these sites is only 25 km, it is permissible for the purpose of the present study to analyse the data from both sites together. The data for Boulder were provided by WDDC C1 in Edinburgh, Scotland. Boulder is situated approximately 1200 km from the Pacific Ocean and a greater distance from the Atlantic Ocean. The data for both stations are in the form of consecutive hourly mean values of declination (D), horizontal intensity (H) and vertical intensity (Z).

The Chapman-Miller harmonics have been determined for both stations using the least-squares method described by Malin & Schlapp (1980). This method is more simple and direct than the traditional Chapman-Miller method and has the advantage of providing more precisely determined coefficients (see also Sellek & Malin 1982). The data have also been analysed by the fixed solar hour method of Schlapp & Weekes (1973).

3 Results

The lunar tide at a given solar time may be synthesized from the harmonic components given by the least squares method and the variation of the tide throughout the course of a
The lunar tide at midnight

Figure 1. Harmonic dial for $L(D)$ at Irkutsk calculated from 14 yr of data. The 24 dial points represent the amplitude and phase of $L(D)$ at each hour of local solar time. The radius of the circle centred at the coordinate origin is equal to the vector probable error, $\rho$.

day plotted in the form of a harmonic dial. Fig. 1 shows the harmonic dial for the lunar tide in declination, $L(D)$, at Irkutsk as a function of local solar time. The radius of the circle centred at the coordinate origin is equal to the vector probable error, $\rho$, in the determination of the tide at any hour; the error is given in this form for comparison with Malin’s result (see Fig. 2). For a vector to be significantly greater than zero at the 95 per cent confidence limit, its amplitude should exceed $2.08\rho$ and thus $L(D)$ is significant at all hours. Although the midnight tide is small, it is well determined, having an amplitude of $3.79\rho$.

Analysis of the same data set by the fixed solar hour method also indicates a significant value of $L(D)$ at Irkutsk at local midnight. The values found by the two methods are not significantly different from each other.

The midnight tides in $H$ and $Z$ are not significantly different from zero when determined by either the least squares or fixed solar hour method.

Malin’s result (Malin 1970) for 18 months of declination data for Irkutsk, is shown in Fig. 2. Owing to the relatively small amount of data analysed, the vector probable error associated with Malin’s determination of the midnight tide is considerably larger than that obtained here using 14 yr of data, and the midnight tide was found to be not significantly different from zero. Thus the present result represents an improvement on that obtained by Malin. It should be noted, however, that the difference between Malin’s result and the present result is not statistically significant, and there is therefore no contradiction between the two results; the improvement is the result of having more data available for the analysis.

At Boulder the least squares determinations of both $L(D)$ and $L(H)$ are significant at midnight, but that of $L(Z)$ is not. For $L(D)$ the midnight tide equals $4.30\rho$ and for $L(H)$ equals $2.98\rho$. The results of fixed solar hour analysis confirm that $L(D)$ is significant at midnight, but the corresponding $L(H)$ and $L(Z)$ tides are not.
In a separate study (Sellek 1982) the variation of the midnight tide with distance from the coast has been investigated using data from an east-west chain of North American observatories and temporary stations situated near 40°N. The temporary stations, which were established as part of the United States geomagnetic programme for the IGY, are: Beloit (geographic coordinates: 39.5°N, 261.9°E), Burlington (39.8°N, 257.7°E), Carrollton (39.4°N, 266.5°E), Casper (42.8°N, 253.6°E), Espanola (36.0°N, 254°E), Leadville (39.3°N, 253.7°E) and Price (39.6°N, 249.2°E). Because only short runs of data are available for each station, the differencing method described by Sellek (1981) was applied with Tucson (32.2°N, 249.2°E) as reference station to improve the precision of the lunar harmonic coefficients. The Tucson and Fredericksburg (38.2°N, 282.6°E) observatories were also included in the study. If Malin’s assumption that the midnight tide is of purely oceanic origin is valid, this tide would be expected to vary in a systematic way across the continent. For each of the elements $D$, $H$ and $Z$, however, no significant differences in the midnight tides are observed between any pair of stations.

4 Discussion

We have seen in the previous section that, in certain cases at least, observatories very far from the ocean appear to show a significant lunar tide at local midnight when analysed by either the harmonic method or the fixed solar hour method. This could, however, be merely the consequence of the approximations and assumptions associated with both methods,
The lunar tide at midnight

discussed in Section 1. In spite of this, we may make some deductions from the results which have been presented above. One is that there is almost certainly a non-oceanic contribution to the midnight tide at stations like Irkutsk and Boulder which are very far from the coast. This follows from the fact that the fixed solar hour method indicates a midnight tide significantly different from zero. For if the tide were constant round midnight, the assumption of the fixed solar hour method would be valid, and it would give correct results for the midnight tide, but the oceanic contribution would be expected to be zero so far from the coast, in which case the observed tide at midnight must be non-oceanic. On the other hand, if the tide were not constant round midnight, this in itself implies a non-oceanic contribution as the oceanic tide has negligible solar-time modulation. Either way, therefore, one must conclude that there is a non-oceanic contribution. Moreover, if the tide at Irkutsk and Boulder contained an appreciable oceanic component, one would expect substantially larger oceanic contributions at stations nearer the coast, and an appreciable variation in the midnight tide with distance from the coast, which has not been found in this study.

A subsidiary result is that it appears that in the case of \( L(D) \) at Irkutsk at least, the harmonics higher than those determined by the Chapman-Miller and least squares methods do not have an appreciable resultant at midnight. This follows from the fact that there is no significant difference between the results from the least squares and fixed solar hour methods. (Alternatively it could be, of course, that the systematic errors in the two methods are nearly equal, by a perverse chance!)

Further investigations are now being made to examine in more detail whether the lunar tide is constant around midnight, using long series of data and new methods of analysis. It may then be possible to make further progress on the problems of the separation of ionospheric and oceanic dynamos, and of determining the source of the non-oceanic contribution to the night-time lunar geomagnetic tide.

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