DAILY VARIATIONS OF THE GEOMAGNETIC FIELD

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Abstract. The atmospheric dynamo theory of the daily magnetic variations (S) has received substantial support from recent observational and theoretical work. In particular, several features of the variations, such as their remarkable enhancement close to the dip equator and other effects indicating a strong control by the main geomagnetic field, are well explained by the dynamo theory. Also the detection of ionospheric currents by instrumental rockets has confirmed an essential part of the theory.

Considerable impetus was given to their study by the acquirement of much new data on magnetic variations during the IGY-IQSY period. Additional observations in the Pacific area were obtained during the IQSY by the establishment of four island stations equipped with newly developed magnetometers. A major advance at other stations was the development of automatic standard observatories using nuclear magnetometers.

Several methods for the world-wide analysis of the S-field have been developed. A possibility now being studied is the completely automatic evaluation and construction by computers of ionospheric current charts for any day and any epoch UT.

Some theoretical and statistical papers are briefly reviewed. These include discussions of the day-to-day variability of S, seasonal changes of the S-field, the nature of the equatorial electrojet, the possibility of solar wind effects contributing to the daily variations, and the modification of the dynamo theory to take account of the possible flow of electric current from the ionosphere along magnetic lines of force in the magnetosphere.

Finally, an attempt to extend the dynamo theory of S by treating the ionosphere as a three-dimensional medium, instead of regarding it as a thin shell, has revealed that, although the relations between the horizontal components of electric field and current density in the dynamo layer are given with reasonable accuracy by the well-known layer equations, the assumption, implicit in the thin shell treatment, that the horizontal currents are non-divergent is not in fact true. Hence a revision of some earlier theoretical work on S appears necessary.

1. Introduction

The daily variations of the geomagnetic field, discovered from observations of compass needle motions by Graham in 1722 (GRAHAM, 1724) have been the subject of many elaborate and extensive studies since that date. Their general form (in all three magnetic elements) at stations distributed throughout the world is now well known, as is also their dependence on season and the solar cycle. This dependence suggests that they are associated with radiative emissions of some kind from the sun, and led STEWART (1882) to put forward the theory that the variations are due to electric currents induced by dynamo action in some conducting layer of ionised gas (then unknown) on the sunlit side of the upper atmosphere, by a regular system of winds carrying the conducting gas across the lines of force of the main geomagnetic field.

Support for this idea came many years later, when the successful transmission of radio waves across the Atlantic by Marconi led HEAVISIDE (1902) and KENNELLY (1902) to suggest the existence of a conducting layer – the ionosphere – to account
for the reflection of radio waves. The first detailed observations of the ionosphere, using radio techniques, were made by Appleton and Barnett (1925), and Breit and Tuve (1925). These, together with many subsequent observational and theoretical studies of the conducting properties of the various layers of the ionosphere now known to exist, have led to the view that the currents mainly responsible for the daily variations flow horizontally at about 100 km height, i.e., in the E-layer. This view has received strong support from the detection of horizontal ionospheric currents at about this height, and their measurement *in situ* by means of instrumented rockets (Singer et al., 1951; Cahill, 1959; Burrows and Hall, 1964; Davis et al., 1966; Davis et al., 1967).

Before Balfour Stewart put forward his idea of an atmospheric dynamo to account for the magnetic daily variations, several other theories had been proposed for them. These earlier theories, together with two others – the ‘drift current theory’ and the ‘diamagnetic layer theory’ – were discussed by Chapman and Bartels (1940), who concluded that, while several of these theories led to daily variations somewhat similar in form to the observed variations, none of them gave an effect sufficiently large to account for the observations. More recently, it has been suggested by Mead (1964) that the current system produced by the solar wind at the boundary of the magnetosphere would lead to a daily variation of the magnetic field at the earth’s surface. His calculations showed, however, that its amplitude would be much too small to account for the observed variations. It thus appears that the dynamo theory is the only theory at present capable of explaining adequately the actual daily magnetic variations. There have, indeed, been a number of difficult problems to resolve in developing the theory to its present detailed form, but it is now generally accepted as the correct explanation of the phenomenon.

Besides the daily magnetic variation having a period of one solar day (and consequently denoted generally by $S$), there is also a systematic though smaller periodic variation, discovered by Kreil (1839), called the lunar daily magnetic variation and denoted by $L$. This variation is associated with the period of rotation (about 24 h 50 m) of the earth relative to the moon, but, strictly speaking, it is a lunisolar variation, since the changes that occur throughout the lunar month reveal that the variation is greatly enhanced during the daylight hours.

The source of the $L$ variations is believed to be an atmospheric dynamo similar to that which gives rise to the $S$ variations. The air motions in the case of $L$ are probably entirely due to gravitational tides, since the moon could hardly affect the atmosphere appreciably in any other way. The possibility of thus distinguishing clearly between the effects of lunar tidal motions and the day and night variations of ionospheric conductivity makes the quantitative theoretical treatment of $L$ rather more satisfactory than that of $S$. On the other hand, more elaborate methods of analysis are required to extract the lunar variations from other variations at any station, so that the errors in the determination of the actual field are likely to be considerably greater than those for the $S$ field.

It should be added that, in the case of both $S$ and $L$, there is a significant contribution to the field from the electric currents that are induced in the earth (including the