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Magnetic satellite missions: where have we been and where are we going?

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Abstract

High-quality magnetic observations have been obtained in recent years from a number of satellite missions. I discuss here the issues regarding the multi-year low-orbit satellite missions: Ørsted, CHAMP and SAC-C, and briefly what is expected from the European Space Agency's forthcoming Swarm constellation. The magnetic satellite data, combined with ground-based data, have provided unique opportunities for studying the core magnetic field and its secular variation, core flow, mantle conductivity and lithospheric composition, as well as the dynamics of the ionospheric and magnetospheric currents. A few examples of recent improvements in our knowledge of the magnetic field are presented, together with future investigations in measuring and modelling the Earth's magnetic field. ***To cite this article: M. Mandea, C. R. Geoscience 338 (2006).***

Résumé

Missions satellitaires magnétiques : où en sommes-nous et où allons-nous ? Au cours des dernières années, des observations magnétiques de très grande précision ont été fournies par quelques missions satellitaires. Nous présentons les résultats majeurs obtenus au cours de ces récentes missions satellitaires : Ørsted, CHAMP et SAC-C, ainsi que ceux attendus de la prochaine constellation Swarm, initiée par l'Agence spatiale européenne. Les données magnétiques satellitaires, combinées avec des mesures au sol, ont permis d'étudier d'une façon unique le champ nucléaire et sa variation séculaire, les mouvements de fluide à la surface du noyau, la conductivité du manteau et la composition de la lithosphère, aussi bien que la dynamique des courants ionosphériques et magnétosphériques. Quelques-uns des exemples les plus représentatifs concernant notre connaissance du champ magnétique sont présentés, mais aussi les améliorations possibles de la mesure et de la modélisation du champ magnétique terrestre. ***Pour citer cet article : M. Mandea, C. R. Geoscience 338 (2006).***
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Mots-clés : Géomagnétisme ; Satellite ; Ørsted ; CHAMP ; SAC-C ; Champ du noyau ; Variation séculaire ; Champ lithosphérique ; Champ externe

1. Introduction

The Earth's magnetic field is used as a basis for probing the Earth's lithosphere and deep interior and

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understanding solar-terrestrial coupling; it is also a tool for navigation, directional drilling, mineral exploration, geomagnetically induced currents and satellite operations. The geomagnetic field is mainly generated by a geodynamical mechanism in the liquid, metallic, outer core. To this dominant part of the Earth's magnetic field must be added the lithospheric contribution due to rocks that formed from the molten state and thus contain information about the magnetic field at the time of their solidification. In addition, a third important contribution is produced by the solar wind varying in intensity and speed with the amount of Sun surface activity encountering the Earth's magnetic field, known as external field.

Measurement of the geomagnetic field at a given time and location combines the resulting value of fields having different origins, as discussed above, namely: (1) the core field known also as the main field, generated in the fluid outer core, (2) the lithospheric field, generated by magnetized crustal rocks, (3) the external field, generated by ionospheric and magnetospheric currents, and (4) the electromagnetic induction field, generated by currents induced in the crust and the mantle by the time-varying external field. Separating these contributions is not an easy task [20]. However, in 1838, C.F. Gauss, using spherical harmonic expansion of the geomagnetic field, developed a method to describe the geomagnetic field globally, providing a rough separation between internal and external contributions to the field.

The geomagnetic field is also subject to temporal variations over various time scales. The so-called short-term variations are detectable over time scales ranging from ∼0.01 s to decades. The very short period variations (seconds to hours) are usually attributed to the Earth's external sources, while the longer-period variations (annual to decadal) are due to solar cycle variations and its harmonics, superposed on the core field temporal variation. The latter is known as the secular variation.

Observations of the full vector magnetic field exist for more than a century, with the first magnetic observatory installed by C.F. Gauss in Göttingen, in 1832. In addition to the observatory network, vector measurements provided by satellites and available since 1979 have greatly improved our knowledge of the geomagnetic field all over the globe. In the following sections, a discussion about the different kinds of measurements is provided, with an emphasis on the role of the latest satellite missions, Ørsted, CHAMP and SAC-C, for providing a better description the Earth's magnetic field.

2. Measuring the Earth's magnetic field: from ground-based observatories to satellite missions

Historically, the role of magnetic observatories was to monitor the secular change of the geomagnetic field, and this remains one of their most important tasks. Some observatories installed at the end of 19th century, provide, nowadays, long-time series. An example is the Chambon-la-Forêt observatory series, covering a total time span of 123 years when the present site measurements (1936–present) are combined with prior nearby measurements made in Saint-Maur (1883–1900) and Val-Joyeux (1901–1935). Today, some 200 observatories are operated worldwide (Fig. 1). To run a magnetic observatory generally involves continuous variation measurements of three field components (one-minute or even one-second data sampling), which are recorded automatically by fluxgate magnetometers. However, these instruments are subject to drifts arising from sources both within the instrument (e.g., temperature effects) and the stability of the instrument mounting. These measurements do not provide absolute values and the instruments are known as variometers. Absolute measurements of the full vector field, sufficient in number to control the instrumental drift, are necessary to calibrate the variometer recordings. Modern land-based magnetic observatories all use similar instrumentation to produce similar data products. For a full description, see [12] and also the INTERMAGNET web site (http://www.intermagnet.org). The fundamental measurements recorded are one-minute values of the vector components and scalar intensity. The one-minute data are important for studying variations in the external magnetic field, in particular the daily variation and magnetic storms. From the one-minute data, hourly, daily, monthly and annual mean values are produced. The monthly and annual mean values are used to determine the secular variation originating inside the Earth's core. The quality of secular-variation estimates therefore critically depends upon the quality of the absolute measurements at each observatory.

Since the 1960s, the Earth's magnetic field intensity has been measured intermittently by satellites. Only recently have there been several missions dedicated to measuring the full field vector, using star cameras to establish the direction of a tri-axial fluxgate sensor. An absolute intensity instrument is also carried to calibrate the vector instrument, and both magnetic instruments are kept remote from the spacecraft by mounting them at the end of a few metre-long non-magnetic boom. The first satellite that provided valuable vector data for geomagnetic field modelling was the MAGSAT mission [14],