doi:10.5047/eps.2013.10.004

Preface

By the stifled voice of the magnetic needle, the
Earth proclaims the movements of her interior,
and could we rightly interpret the flaming page of
the polar light, it would not be less instructive for us.

Christopher Hansteen, Norwegian Physicist (1784–1873)
student of Hans Christian Ørsted (1777–1851)

Magnetic fields play a major role among the forces that control the motion of matter everywhere in the Universe. Also on our planet the magnetic field represents the major forces that determine the magnetosphere and control our electromagnetic environment from the upper, conducting, part of our atmosphere to its boundary. Nevertheless, our understanding of the origin of the magnetic field and its dynamics, not to speak of the ability to predict its evolution, is poor.

Einstein once ranked the problem of origin of the Earth's magnetic field among the three most important and unsolved problems in physics. In Einstein's time scientists went so far as to postulate new physical laws in order to explain the phenomenon of geomagnetism. Today we are close to having global data with the necessary resolution in time and space—and computational power to perform advanced geodynamo simulations—to be able to validate many of the theories and models regarding the origin of the magnetic field and its dynamics.

But the geomagnetic field is not only relevant for understanding the solid earth. The geomagnetic field interacts with the varying solar wind and thereby creates the ever-changing magnetosphere. Solar-terrestrial science has attracted much attention during recent years, among scientists as well as in the public. The magnetosphere and the upper atmosphere in the polar regions are the locations where the effects of the variable Sun are most clearly seen. At present, our understanding of the global processes that determine the coupled interaction between the electromagnetic and corpuscular emissions from the Sun and the neutral and ionized species in the Earth's environment is too poor to predict the response of the system to changes in the solar output. As a consequence, several international research programs have been initiated to improve our knowledge of the solar-terrestrial system. The European Space Agency's *Swarm* mission—at the time of writing literally on the launch pad—represents the most advanced monitor of the near Earth global magnetic field and its variations.

During the last nearly 15 years the Ørsted and CHAMP spacecraft have been crucial for producing the geomagnetic field models that are used extensively in research and applications. The *Swarm* mission with its improved instrumentation and its carefully designed constellation of three satellites will not only improve the knowledge of the magnetic field but will also provide the possibility to detect the core field variation with an unprecedented resolution in time and space. This will lead to major advancements in our knowledge regarding the origin and dynamics of the geomagnetic field. The scientific community organised in The International Association of Geomagnetism and Aeronomy (IAGA) has strongly supported the mission and looks forward to receiving the wealth of highly accurate data that the mission will provide.

In order to take optimal advantage of the unique constellation aspect of the *Swarm* mission, implemented as part of the European Space Agency's Living Planet programme and targeted for launch in November 2013, considerably advanced data analysis tools have been developed. Scientific users of data from the *Swarm* mission will therefore benefit significantly from free and open access to such derived products, so-called Level 2 data, that take into due account the constellation features. This facility, called "*Swarm Satellite Constellation Application and Research Facility*" (SCARF), has been developed, tested and validated by a consortium of six research institutions under a contractual agreement with the Agency. This service is planned to be operational for a period of 5 years after the launch of the *Swarm* mission, including processing of 4 years nominal mission data. ESA will provide all data products through the archiving and dissemination infrastructure of the *Swarm* mission. The main aim with this facility is to derive in an operational way the basic elements in form of sources that constitute the measured magnetic field, from the core, the mantle, the crust and the various current systems above the Earth's surface, maintained by the radiation and plasma flow from the Sun.

In this issue of *Earth, Planets and Space* each of the *Swarm*-based products is described in one or more articles dealing with the scientific rationale, the methodology and limitations of the derivation, and the potential use in the form of examples of science investigations and applications.

To help give the reader an overview of the various products and their relevance we briefly summarize the special issue here. A more comprehensive description of the mission and the various science products in SCARF are presented in the overview paper (Olsen *et al.*, 2013).

Several different techniques are being used to derive the core field, which represents the major part of the geomagnetic field. The rapid evolution in computer performance now makes it possible to model a huge number of parameters representing all sources, provided sufficient measurements are available. This comprehensive approach (Sabaka *et al.*, 2013), has shown increasing performance during recent years due to innovative ways of handling the measurements and their intrinsic dependencies. But for some specific tasks and investigations other methods may be preferable as described by Rother *et al.* (2013). The main contribution to the magnetic field from the mantle is from currents in the conducting minerals since the temperature is generally too high to allow remnant magnetism. As opposed to the currents in the outer core, which involve moving material, the currents in the mantle are induced by variations in the electrical currents outside the Earth. Sophisticated algorithms have been developed (Püthe and Kuvshinov, 2013a, b; Velímský, 2013) which, for the first time, will provide an estimate of the 3-dimensional structure of the electric conductivity in the Earth's mantle. This is important for a number of geophysical science disciplines concerned with the temperature and composition of the mantle. The outermost part of the solid Earth, the crust, is characterized by strong, local magnetic fields due to the various minerals located there. These are therefore of great interest in geophysical exploration. The science and the methodology to derive global maps of the crustal magnetic field is provided by the comprehensive inversion (Sabaka *et al.*, 2013) as well as by a dedicated method taking specific advantage of the two side-by-side spacecraft providing the gradient of the magnetic field (Thébault *et al.*, 2013). The magnetic field from currents outside the Earth are significantly smaller but highly variable as they are greatly influenced from the Sun. Some of the variations are regular, connected to the rotation of the Earth, for example some of those originating in the ionosphere (Chulliat *et al.*, 2013). Others are rather directly connected to variations in the solar wind, for example the currents in the magnetosphere (Hamilton, 2013) and the field-aligned currents connecting the magnetosphere to the auroral oval in the ionosphere (Ritter *et al.*, 2013). It should be noted that the *Swarm* spacecraft together with the highly accurate magnetic field instruments also include an electric field instrument, the first of its kind in space. The underlying science and the methodology used in this instrument is described in Alken *et al.* (2013). Furthermore, each *Swarm* satellite carries an accelerometer that is used to retrieve thermospheric mass density and winds (Visser *et al.*, 2013). A phenomenon of interest for signal propagation in the ionosphere is caused by the so-called ionospheric bubbles, which can be deduced from magnetic field and plasma observations (Park *et al.*, 2013).

When deriving physical parameters from measurements in an operational manner, it is essential to repeatedly check the quality and the scientific consistency of the derived products. Beggan *et al.* (2013) explain the validation steps for each magnetic field product and the comparison against independent datasets. The paper describes the formal quality assurance steps that are carried out prior to releasing the data to the user community. Crucial for an optimal use of the spacecraft observations is the availability of ground based magnetic observatory data, both for selecting the appropriate spacecraft data for specific analyses and for direct use together with *Swarm* data in scientific investigations (Macmillan and Olsen, 2013). Traditionally, definitive geomagnetic observatory data are not readily available due to the careful and time consuming required calibration, which is not always available at short notice. For immediate use in support of rapid modelling efforts, it may be sufficient to use so-called quasi-definitive observatory data. These can be quickly produced and delivered in support of *Swarm* as proposed by Clarke *et al.* (2013).

"Space Weather" is attracting increasing attention due to the growing dependence of our global and regional infrastructure on information from Earth orbiting satellites. Stolle *et al.* (2013) present an overview of potential applications of data from the *Swarm* mission for space weather purposes, also in association with other ground-based and space-based data sets. Recently automated methods of deriving the characteristics of magnetic pulsations in the magnetosphere have been proposed (Balasis *et al.*, 2013), which could be effectively applied to the huge datasets from *Swarm* to retrieve, in an operational way, new information about our electromagnetic environment.

The papers contained in this issue represent a large, coherent, and dedicated effort by the *Swarm* science community to derive a set of products that together provide the best possible description of the contributions from the various sources of the measured magnetic field at the three satellites. The aim is not only to produce the best standard models but perhaps more importantly, to make these models of the sources of the geomagnetic field available (see http://earth.esa.int/swarm) to the scientists in a wider scientific community who may not have the background to produce such models themselves but who will be able to use the models as basis for subsequent advanced science investigations as well as various and innovative applications. The success of the effort to establish the *Swarm* SCARF virtual datacentre demonstrates the readiness of the community to take advantage of the *Swarm* Mission as soon as data begin to flow. We thank all the authors and the reviewers as well as the editorial board of EPS and Terra Scientific Publishing Company (TERRAPUB) for their efforts on this special issue. We will be delighted if this EPS special issue helps to stimulate the use of the *Swarm* SCARF Level 2 data products and provides a handy collection of the fundamental elements and potential applications that this unique data set will represent.

Guest Editors: Eigil Friis-Christensen
Rune Floberghagen

References

Alken, P., S. Maus, P. Vigneron, O. Sirol, and G. Hulot, Swarm SCARF equatorial electric field inversion chain, *Earth Planets Space*, **65**, this issue, 1309–1317, 2013.

Balasis, G., I. A. Daglis, M. Georgiou, C. Papadimitriou, and R. Haagmans, Magnetospheric ULF wave studies in the frame of Swarm mission: a time-frequency analysis tool for automated detection of pulsations in magnetic and electric field observations, *Earth Planets Space*, **65**, this issue, 1385–1398, 2013.

Beggan, C. D., S. Macmillan, B. Hamilton, and A. W. P. Thomson, Independent validation of Swarm Level 2 magnetic field products and 'Quick Look' for Level 1b data, *Earth Planets Space*, **65**, this issue, 1345–1353, 2013.

Chulliat, A., P. Vigneron, E. Thébault, O. Sirol, and G. Hulot, *Swarm* SCARF Dedicated Ionospheric Field Inversion chain, *Earth Planets Space*, **65**, this issue, 1271–1283, 2013.

Clarke, E., O. Baillie, S. J. Reay, and C. W. Turbitt, A method for the near real-time production of quasi-definitive magnetic observatory data, *Earth Planets Space*, **65**, this issue, 1363–1374, 2013.

Hamilton, B., Rapid modelling of the large-scale magnetospheric field from Swarm satellite data, *Earth Planets Space*, **65**, this issue, 1295–1308, 2013.

Macmillan, S. and N. Olsen, Observatory data and the Swarm mission, *Earth Planets Space*, **65**, this issue, 1355–1362, 2013.

Olsen, N., E. Friis-Christensen, R. Floberghagen, P. Alken, C. D Beggan, A. Chulliat, E. Doornbos, J. T. da Encarnação, B. Hamilton, G. Hulot, J. van den IJssel, A. Kuvshinov, V. Lesur, H. Lühr, S. Macmillan, S. Maus, M. Noja, P. E. H. Olsen, J. Park, G. Plank, C. Püthe, J. Rauberg, P. Ritter, M. Rother, T. J. Sabaka, R. Schachtschneider, O. Sirol, C. Stolle, E. Thébault, A. W. P. Thomson, L. Tøffner-Clausen, J. Velímský, P. Vigneron, and P. N. Visser, The *Swarm* Satellite Constellation Application and Research Facility (SCARF) and *Swarm* data products, *Earth Planets Space*, **65**, this issue, 1189–1200, 2013.

Park, J., M. Noja, C. Stolle, and H. Lühr, The Ionospheric Bubble Index deduced from magnetic field and plasma observations onboard *Swarm*, *Earth Planets Space*, **65**, this issue, 1333–1344, 2013.

Püthe, C. and A. Kuvshinov, Determination of the 1-D distribution of electrical conductivity in Earth's mantle from *Swarm* satellite data, *Earth Planets Space*, **65**, this issue, 1233–1237, 2013a.

Püthe, C. and A. Kuvshinov, Determination of the 3-D distribution of electrical conductivity in Earth's mantle from *Swarm* satellite data: Frequency domain approach based on inversion of induced coefficients, *Earth Planets Space*, **65**, this issue, 1247–1256, 2013b.

Ritter, P., H. Lühr, and J. Rauberg, Determining field-aligned currents with the Swarm constellation mission, *Earth Planets Space*, **65**, this issue, 1285–1294, 2013.

Rother, M., V. Lesur, and R. Schachtschneider, An algorithm for deriving core magnetic field models from the Swarm data set, *Earth Planets Space*, **65**, this issue, 1223–1231, 2013.

Sabaka, T. J., L. Tøffner-Clausen, and N. Olsen, Use of the Comprehensive Inversion method for *Swarm* satellite data analysis, *Earth Planets Space*, **65**, this issue, 1201–1222, 2013.

Stolle, C., R. Floberghagen, H. Lühr, S. Maus, D. J. Knudsen, P. Alken, E. Doornbos, B. Hamilton, A. W. P. Thomson, and P. N. Visser, Space Weather opportunities from the *Swarm* mission including near real time applications, *Earth Planets Space*, **65**, this issue, 1375–1383, 2013.

Thébault, E., P. Vigneron, S. Maus, A. Chulliat, O. Sirol, and G. Hulot, Swarm SCARF Dedicated Lithospheric Field Inversion chain, *Earth Planets Space*, **65**, this issue, 1257–1270, 2013.

Velímský, J., Determination of three-dimensional distribution of electrical conductivity in the Earth's mantle from Swarm satellite data: Time-domain approach, *Earth Planets Space*, **65**, this issue, 1239–1246, 2013.

Visser, P., E. Doornbos, J. van den IJssel, and J. T. da Encarnação, Thermospheric density and wind retrieval from Swarm observations, *Earth Planets Space*, **65**, this issue, 1319–1331, 2013.