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First ideas about a

Kittel 2071

Center for Satellite Gravity and Magnetic Data Analysis. (SAGRAMADA)

By

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(with augmentations by Nils Olsen, DSRI)

1. Introduction.

Recently the Ørsted Satellite has been successfully launched, collecting high quality magnetic data. In the next few years 4 satellite missions (CHAMP, SAC-C, GRACE, GOCE) will be launched mapping the gravity field, and two of these missions also carry instrumentation for mapping the magnetic field.

Decade of Geoptential Research ...

Outside their respective source regions (mass density is the source of the gravity field, and electric currents are the sources of the magnetic field), both the gravity and the magnetic field are potential fields and may be described with similar mathematical models. Therefore the models can be determined using similar methods.

Generic methods for handling potential field data have been developed, also by Danish scientists. These methods can account for various types of data errors. However, the methods have only been used on small (for instance regional) data sets. The limitation being for the moment the size and speed of computers.

In Denmark there exist expertise in handling satellite data, but the new missions poses new challenges. Firstly, a vast amount of data will be collected, which will require that sophisticated mathematical methods are put into use to analyse these data. Secondly, only the static part of the gravity field have traditionally been modelled using spherical harmonic analysis (SHA), however we are now able to map time variations in the gravity field. For the magnetic field, time variation of the long-wavelength (>3000 km) part has been modelled using SHA, but data from the present and upcoming satellite missions allow for the inclusion of much higher harmonics.

Despite the vast amount of data which will be collected, the orbit chosen for the mentioned missions implies that an area around the geographic poles will not be covered. Here ground data, collected e.g. by aircraft, may be used to cover the polar caps. Ground data may also be used to calibrate and validate the satellite data.

Danish scientists are already deeply engaged in the analysis of Ørsted data, and participate in the preparation of other satellite missions. (C.C. Tscherning (Department of Geophysics, DG) is member of the ESA Mission Advisory group for GOCE, P. Knudsen (Kort og Matrikelstyrelsen, KMS) participates in the teams analysing GRACE data, and N. Olsen (Danish Space Research Institute, DSRI) is Project Scientist of Ørsted-2/SAC-C).

We are thus faced with a situation where there exist a very good opportunity for Danish scientists to exploit new data sets and to develop and apply new techniques for geopotential research as part of their efforts of modelling and interpreting the data.

2. Scientific tasks.

2.1. Analysis of satellite gravity and magnetic data.

In the 60'ties a Danish Scientist, T. Krarup, developed a general method, *Least-Squares Collocation (LSC)*[1], which enables the simultaneous treatment of many data types (associated with the same physical phenomena), the treatment of systematic and random errors and furthermore determining parameters associated with the phenomena. The method has been implemented and further developed both internationally and in Denmark at KMS and at the GD. Independent of this, a similar method[2] has been developed in the 80ties for the analysis of data from Magsat, which was the first geomagnetic mapping mission. Since the aim is to find the smoothest harmonic function (on a sphere) which is compatible with the data, this method has been called *Harmonic Splines.*

The method is an optimal estimation method, but requires *a-priori* knowledge of the variability (observational error, contribution from unmodeled signals, ...) of the phenomena. This is expressed through a general covariance model. The use of the method in its strict formulation requires the solution of as many unknowns as there are observations and is therefore not feasible using present day computers.

Therefor three main tasks must be solved:

(1) How do we effectively reduce the numerical effort without degrading the result,

(2) *A-priori information:* How do we obtain a satisfactory covariance model which represents the global variability of the variations of the gravity and the magnetic fields.

(3) How de we handle systematic errors, and random errors of non-uniform (for instance anisotropic) character.

2.2. Modelling the fields.

Traditionally the gravity and the magnetic fields have been modelled using spherical harmonic expansions. However the fields are varying with time, and this gives a new dimension to the modelling. Solutions do exist for the magnetic field, and they may probably be taken over by the modellers of the time variations of the gravity field.

The vast amount of data will probably also make the use of spherical harmonics unfeasible. Alternative methods must be found, e.g. regional representations. This may also be of

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1 ...

2 Backus, Shure, ...

advantage if satellite data are to be combined with data at the surface of the Earth.

2.3. Collection and analysis of auxiliary data.

Due to the inclinations of the satellites data gaps will occur near the geographic poles. For gravity data an international effort, lead by KMS, assembling all data in the Arctic will be completed in 2000. However, on Antarctica the situation is very different. New surveys, for instance using airborne instrumentation, must be performed. Using the expertise obtained by KMS, Denmark may here take part in the data collection and the analysis of the data. Magnetic field data may be collected simultaneously with the gravity data.

In this area an ongoing research effort by KMS in improving airborne methods may be further enhanced.

2.4. Interpretation.

The advent of new global high quality gravity and magnetic data gives an opportunity to solve a number of tasks with improved results as compared to earlier efforts.

For the gravity field:

- Connection of height datum between continents and between islands and continents.
- Improved determination of the geoid using local data.
- Improved inertial navigation and interial aided kinematic positioning.
- Better determination of the rock bottom of ice-covered areas (Antarctica).
- Improved determination of sea-surface topography, and thereby of ocean mass transport.

The availability of time-varying fields opens new problems of interpretation:

- Changes due to (large) Earthquakes.
- Changes caused by increase/decrease of glaciers and ice-caps.
- Changes due to increased or decreased sea level.

And for the magnetic field:

- using a-priori information about core dynamics (for instance geostrophic flow, frozen flux condition, ...) to constrain the time variation of the core field.
- study of mantle conductivity using the above mentioned advanced geopotential methods (electromagnetic induction due to time varying ionospheric and magnetospheric current systems).
- Better description of the lithospheric field.
- Correlation between secular variation and Earth Rotation changes (Length of Day).

3. Resources available and needed.

The Department of Geophysics, KMS and the Danish Space Research Institute carry out research of fundamental character related to the above described research objects. The current effort correspond to totally to 5 man years. 3 PhD-students are currently engaged in projects associated with the above mentioned subjects. Only 2 man-year are at present directly dedicated to the subjects.

In order to start a serious effort in the area in a 5 year period it is necessary to have the following resources:

DSRI: 1 Post-Doc, 1 PhD-student

DG: 1 Post-Doc, 2 PhD-students

KMS: 1 Post-Doc, 1 PhD-student.

Access to large scale computer facilities must be ensured, and necessary ordinary computational facilities must be available.

A restricted data-collection effort should be made in Antarctica, with air-borne gravity and magnetic data collection (1 month in 2 summers).

The organisatorical frame should be a Centre with the 3 institutions as participants, physically located at the Rockefeller Complex. Agreements of co-operation already exist between DG and the two other institutions. Co-operation with other institutions may be possible (DMI).

Conclusion.

A great opportunity exist for Danish Geophysical science. New satellite data give a challenge for using advanced mathematical methods. Many open questions about these methods must be answered.

The data gives new possibilities for interpretation. Putting in a special effort here, will give us a possibility for being in the front-line of the current gravity and magnetic field research.

Subject:
Date: Sun, 2 Apr 2000 14:17:23 +0200 (MET DST)
From: Nils Olsen <nio@dsri.dk>
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Kaere Rene og Carl-Christian,

som aftalt i sidste uge har jeg skrevet omtrent en halv side om "geomagnetic potential research" - se den foerste side af vedhaeftet WORD 97 document. Resten af dokumentet er CCT's udkast, hvori jeg (inden vi besluttede at det hele skal skrives om) har lavet nogen rettelser/tilfoejelser.

Med hensyn til et moede i denne uge saa passer det mig bedst enten paa tirsdag (dog ikke mellem 14:45 og 16:30) eller paa onsdag. Torsdag og fredag er jeg meget optaget.

Med venlig hilsen
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(2/4 2000, Nils Olsen)

Research in global and regional geomagnetic potential fields

At the Earth's surface, the magnetic field is always a potential field. At satellite altitude, however, this assumption is violated if the satellite flies through electric currents, which occurs especially at polar latitudes during geomagnetic disturbed conditions. Nevertheless, the estimation of that part of the observed magnetic field which can be derived from a scalar (laplacian) potential is the primary goal of all high-precision geomagnetic missions.

Spherical harmonic expansion is the classical method for estimating the potential. Contrary to an expansion of the gravity field, for which coefficients up to degree and order of a few hundreds are estimated, the dynamic behaviour of external (magnetospheric and ionospheric) current systems limits the expansion to degree and order less than, say, 60; at least with data from single satellite missions.

In addition to modelling the static part of the magnetic potential, modelling its time variation is usually also done with spherical harmonics for the spatial expansion and Taylor series or splines for the temporal expansion. Although knowledge of ionospheric and magnetospheric current systems has been successfully used to constrain the expansion of external sources, physical constraints for the expansion of the secular variation of the core field have only been used roughly, if at all. For instance: the core field obeys the frozen flux conditions, at least at time scales shorter that one century. Assuming geostrophic or tangential fluid motion at the top of the core are other, even more restrictive, conditions. Assumptions on the electrical conductivity of the deep mantle can be used the distinguish between the short-term variation of the core field and the induced contribution of the solar-cycle variability of external sources. Some of these constraints are easier to apply in the spectral domain of a spherical harmonic expansion, whereas for other constraints and expansion using alternate methods, like spherical splines, are more suitable. The assumption of geostrophic flow, for instance, may be valid in a certain latitude band only.

Possible research areas:

- Using a-priori information about core dynamics (for instance geostrophic flow, frozen flux condition, ...) to constrain the time variation of the core field.
- Electromagnetic induction studies using advanced geopotential methods like harmonic splines. Both induction due to time varying ionospheric and magnetospheric current systems and due to the secular variation of the core flow require a good description of the time-space structure of the geomagnetic field.
- Better description of the lithospheric field. It is generally believed that spherical harmonic expansion coefficients below degree/order 12 are dominated by the core field, whereas those above degree/order 14 are dominated by the crustal field. However, for the secular variation the situation is different, since the lithospheric field is time independent (apart from induced magnetization). Only satellite data enable to estimate the temporal variation at degree/order above 10, and a determination of the secular variation for degree/order up to 20 or so would allow to study core motion in much greater detail as it is possible today.