Introducing POMME, the POtsdam Magnetic Model of the Earth

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Summary. Models of the main and external field play a key role in the analysis and interpretation of satellite, airborne, marine and ground magnetic data. Here, we introduce a series of main field models with several new features: (1) External fields are parametrised in SM and GSM coordinate systems, accounting for the geometry of the ring current, the magnetosphere and the solar wind. (2) We use vector data globally, instead of the usual approach of using vector data at low latitudes and scalar data at high latitudes. (3) The angles between CHAMP's star camera and its vector magnetometer are co-estimated in a joint inversion with Ørsted data. (4) The model includes 2nd time derivatives of the magnetic field to account for the non-negligible secular acceleration in the current period of new magnetic satellite data. As inferred from the degree spectrum of the current version POMME-1.4, the secular variation is stable to degree 11 and the secular acceleration to degree 6.

Key words: geomagnetic field, field models, main field

1 Introduction

Analysis of geomagnetic data usually starts with subtracting a main field model in order to uncover weaker contributions to the magnetic field, such as from mantle induction [2], crustal magnetisation [8], ocean dynamo [11], ionospheric [5] and magnetospheric currents [3]. Main field models thus play a key role in the analysis and interpretation of geomagnetic data. Popular recent models include the comprehensive model CM3 [10], the Ørsted field models [9] and the first official CHAMP main field model CO2 [4]. In view of the general importance of accurate main field models and motivated by the call for candidate models for the 9th generation IGRF, we have developed a new series of main field models which are available at http://www.gfz-potsdam.de/pb2/pb23/SatMag/pomme.html and shall be updated regularly.

2 Model details

The POMME model includes a parametrisation of the internal field, external static magnetospheric field, ring current field (including induced part) and co-estimated corrections for the angles between the CHAMP star camera and vector magnetometer reference systems.

2.1 Internal field

The internal field is parametrised in the usual way as

$$V(r,\vartheta,\varphi) = a\sum_{\ell=1}^{\infty}\left(\frac{a}{r}\right)^{\ell+1}\sum_{m=-\ell}^{\ell} g_\ell^m Y_\ell^m(\vartheta,\varphi), \tag{1}$$

with the scalar potential V of the magnetic field, $\mathbf{B} = -\nabla V$, colatitude ϑ, longitude φ, degree ℓ, order m, reference radius $a = 6371.2$ km, and Gauss coefficients g_ℓ^m, where coefficients with negative order are often called h in geomagnetism. Finally, Y_ℓ^m are Schmidt quasi-normalised spherical harmonics [1].

Accounting for the rapid change of the core field, each Gauss coefficient is given as a truncated Taylor expansion

$$g(t) = g + tg' + 0.5t^2g''. \tag{2}$$

For the current version (POMME-1.4), g and g' are given to degree and order 15, while the secular acceleration g'' extends to degree and order 10 (Figure 1).

2.2 Static magnetospheric field

In all existing geomagnetic field models the magnetospheric fields are given in Earth fixed coordinates. Hence, they are assumed to co-rotate with the Earth. This means, in particular, that daily and seasonal variations have to be introduced in order to be able to describe static magnetospheric fields. This reminds of the pre-Kepler practice of describing the movement of planets in an Earth fixed coordinate system. In order to describe magnetospheric fields in the natural coordinate systems of their source currents, POMME forsees

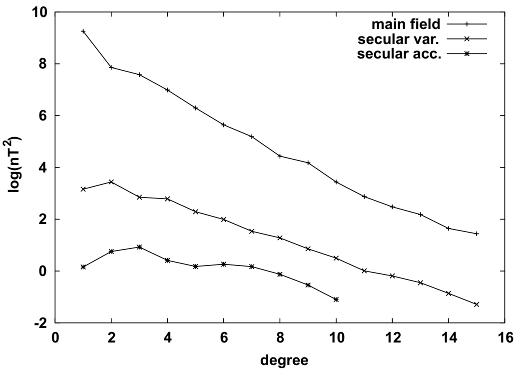

Fig. 1. Power spectra of the POMME-1.4 core field, its secular variation and the secular acceleration. The secular variation was damped for degrees 12-15, and the secular acceleration was damped for degrees 7-10.

contributions in Geocentric Solar Magnetospheric (GSM) and Solar Magnetic (SM) coordinates, which are the natural coordinate systems of the magnetosphere and the ring current, respectively. The current version (POMME-1.4) includes a static degree-2 field in GSM. This GSM field appears as an annually, semi-annually and daily varying external field in Earth fixed coordinates (Figure 2). Furthermore, an axisymmetric ring current field is given in SM.

2.3 Ring current field

In main field modelling it is common practice to co-estimate the coupling coefficients between the Dst index and the ring current field. However, since low Dst values are a data selection criterion, this co-estimation does not work very well. We therefore estimate the coupling coefficients from a data set including high Dst and then regard these coefficients as fixed. We find the optimum values for the external (q_1^0) and internal (g_1^0) dipoles in SM to be

$$q_1^0(t) = 0.76 \cdot Dst(t) \tag{3}$$

$$g_1^0(t) = 0.76 \cdot 0.32 \cdot Dst(t) \tag{4}$$

Figure 3 shows these values in comparison with typical values given by previous field models. Future versions of POMME will include non-symmetric ring current contributions in SM, consistent with the local time dependence found by Schwarte (personal communication).

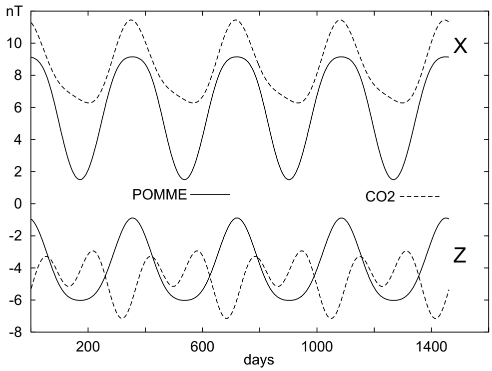

Fig. 2. Annually varying magnetospheric field (without ring current field) predicted by two field models for an observer at 0° longitude and 30° latitude. While the CO2 field model[4] explicitly contains annual and semi-annual coefficients in an Earth fixed reference frame, the model POMME has a static external field in magnetospheric (GSM) coordinates and the annual variations are merely a consequence of the seasonal orientation of the Earth axis in the GSM reference frame.

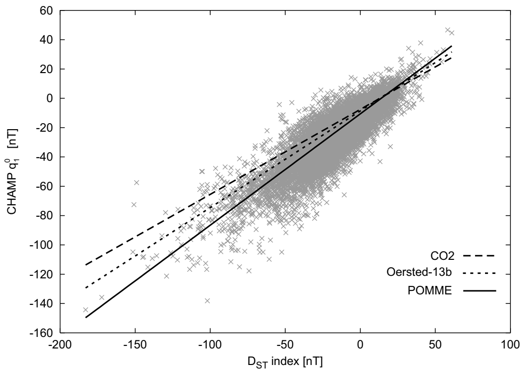

Fig. 3. Usually, the coupling coefficients of the Dst index to the external (q_1^0) and induced (g_1^0) ring current field are co-estimated with the field model coefficients. However, since data are selected for low Dst, the coupling coefficients tend to be biased to small values. For POMME, the coupling coefficients were determined by a visual best fit to a large data set of q_1^0 and g_1^0 estimates. Shown here is only q_1^0.

2.4 Star camera re-calibration for CHAMP

Accurate vector measurements require very accurate knowledge of the satellite orientation (attitude). Attitude uncertainty is the largest source of error in Magsat, Ørsted and CHAMP data. For CHAMP, with its stable attitude, an additional difficulty arises in the calibration of the angles between the star camera and magnetometer reference systems. Due to thermo-mechanical instabilities, these angles vary with time and have to be co-estimated in the inversion for the model parameters. Luckily, the angles appear to be rather stable over time spans of months. ¿From the visual inspection of field residuals, we identified 6 stable time intervals for POMME-1.4. For each interval, three rotation angles are given as a correction of the field vector orientation with respect to the CHAMP satellite. These correction angles should be used in the analysis of CHAMP data. Furthermore it is foreseen that these angles will be used as corrections in producing the final level-3 CHAMP vector data product.

2.5 Data selection for POMME-1.4

In geomagnetic field modelling it is general practice to use vector data at mid latitude and scalar data at high latitudes in order to avoid contamination by field aligned currents. However, the work on the crustal field model MF2 showed that the inclusion of vector data at high latitudes is very well possible if only the quietest tracks are selected by their RMS against an initial field model. Our primary motivation for using vector data at high latitudes for estimating the POMME coefficients is the following: If vector data are available

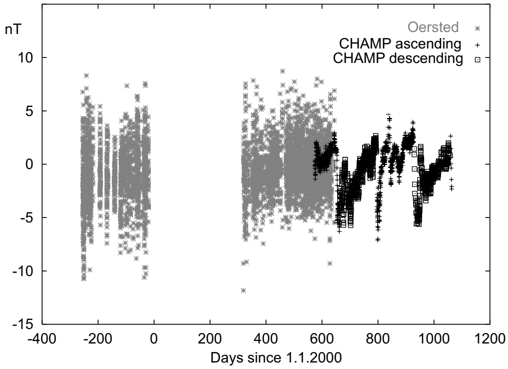

Fig. 4. Data residuals, averaged over 2000 seconds, for the vertical component of the magnetic field against POMME-1.4. During the long empty interval in the year 2000, Ørsted was outside of the 0-6 LT window, which was used here as a data selection criterion. The same LT requirement was applied to the CHAMP data. Hence, not all of the CHAMP data displayed here were actually used. Trends in the residuals may either be local time effects or indicate gradual changes in the angle between the star camera and magnetometer reference systems.

over the entire sphere, internal and external potential fields can be unambiguously separated from toroidal fields [1]. While we are not co-estimating toroidal fields, attitude errors are known to look like toroidal fields and vice versa. Thus, it may be difficult to co-estimate attitude angle corrections if there are no vector data at the high latitudes. For POMME-1.4 we therefore used only vector data, with CHAMP data from 15-May-2001 to 30-Sep-2002 and Ørsted vector data from 21-Apr-1999 to 30-Sep-2002. Due to the occurrence of F-Region currents in the pre-midnight hours [6] which are associated with the diamagnetic effect of ionospheric plasma [7], we used only data in the 0-6 local time (LT) window. Only for the 1999 Ørsted measurements we also included data at 22-24 LT. An earlier POMME version, which was the basis for our DGRF-1995 candidate model, also included observatory annual means. Observatory data help to stabilise secular variation and will again be included in the upcoming versions. Data residuals (Figure 4) are centered around zero. This indicates that the Taylor series to degree-2 for the temporal variation of the Gauss coefficients is adequate for the currently considered time span of 4 years.

3 Conclusion

With POMME we introduce a series of field models for the accurate description of the main and external field. New features include the parametrisation of magnetospheric fields in magnetospheric (instead of Earth fixed) coordinates, the imposing of realistic, fixed coupling coefficients between the Dst index and the ring current field, and the co-estimation of attitude corrections.

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