Responses to comments on "Analysis of Juno perijove 1 magnetic field data using the Jovian paraboloid magnetospheric model" by Ivan A Pensionerov et al. (Manuscript number angeo-2018-82)

Anonymous Referee #2

We are grateful to the Referee for their comments, which have resulted in a number of significant changes in the revised version. The comments are reproduced verbatim in italics, and our replies given step-by-step beneath. The page and line numbers are given for the revised manuscript.

General comments

In this paper the authors present Jovian magnetic field measurements from the middle magneto- sphere collected during Juno perijove 1 pass. The data are analysed in order to determine optimal parameters for the magnetodisc described by the semi empirical global paraboloid Jovian magnetic field model by Alexeev and Belenkaya (2005). This model consists of six components contributing to the total magnetospheric magnetic field (internal field, IMF and different current systems contributions).

In their analysis, the magnetic field data are kept untouched, and the principal contributions to the magnetic field in the observed region (middle magnetosphere) are assumed to be the internal field and the magnetodisc. Only two parameters of the four parameters to describe the magnetodisc are 'fitted' (while there are a total of nine parameters for the global magnetic field). These parameters are the radius of the inner edge of the disc RDC2 and the magnetic field at the outer edge of the magnetodisc BDC, the other two parameters consist of Jupiter's dipole ψ (and is calculated as function of time), and the radius of the outer edge of the disc RDC1 (fixed to the value given by Alexeev and Belenkaya (2005) with data from the inbound trajectory of Ulysses).

Similar studies to estimate the magnetodisc's parameters according to a model have been carried for Jupiter (as well as Saturn) with empirical models such as the CAN disc (Connerney, Acuna and Ness, 1983) using magnetic data from various missions (Voyager, Pioneer, Galileo, Ulysses, Cassini). There are also detailed physical models such as Caudal (1986), and Achilleos, Guio and Arridge (2010) for Saturn to which magnetic data have been compared. This study is carried using magnetic data collected from the on-going mission to Jupiter, Juno. This could potentially contribute and add to the existing knowledge from previous work but I believe that the article in its present form is not acceptable for publication in Annales Geophysicae. But I would encourage the authors to resubmit their paper after implementing the revisions as proposed hereafter.

The referee's description of our paper is mainly correct. We point out, however, that it is shown directly in the paper (Figures 3 and 4 in the revised version) that fields in the regime considered, inside 60 R_J, are indeed dominated by the magnetodisc and planetary fields, such that this is not an assumption as stated above. This finding then makes it reasonable to treat the minor field contributions from the tail and magnetopause currents in an approximate way, by using fixed parameter values set at those determined from the Ulysses inbound pass. These fields are typically at least an order of magnitude less than the magnetodisc field in the middle magnetosphere regime investigated, such that plausible modifications will not change the fit to the magnetodisk field significantly.

Specific comments

In an age where advanced nonlinear fitting programs and methods have never been so easy to access, I find it somehow not acceptable to 'characterise' the best fit of a multi-parameter fit model with a contour plot of the residuals for the two parameters BDC and RDC2 (Fig. 3). I would recommend to try and use a standard nonlinear fitting program implementing a Levenberg Marquardt method or similar, that provides *as well meaningful statistics like error estimates for the parameters. You might be want as well to try and fit RDC1 with such method.*

In response to this comment we have changed the method of parameter optimization to the "Trust Region Reflective" procedure (Branch et al., 1999), as indicated on page 7 lines 9-10. We also newly included R_{DC1} (outer disc radius) into the fit. However, the best R_{DC1} value for all 10 orbits employed in the study was found to be the maximum value set in relation to the size of the model subsolar magnetopause, namely 95 R_J (Table 1 and page 8 lines 1–3).

Branch, M. A., Coleman, T. F., and Li, Y.: A Subspace, Interior, and Conjugate Gradient Method for Large-Scale Bound-Constrained Minimization Problems, SIAM Journal on Scientific Computing, 21, 1–23, https://doi.org/10.1137/s1064827595289108, 1999

Eq. 3 does not make sense in its present form. The numerator under the summation over measurement points is homogeneous to the square of a vector while a scalar is meant: the Euclidean vector norm. It is not clear what is actually fitted, the components of the vector (in what coordinate system?).

In the revised paper the form of the equation, now Eq (4), has been clarified, and its denominator changed from the magnitude of the modelled field to the magnitude of the observed residual field. The calculation was carried through using Cartesian components in the JSM system, but this is actually immaterial since the vector magnitudes employed are entirely independent of the chosen coordinate system.

Figures 4, 5 and 6 all show the amplitude of the magnetic field. It would be more meaningful to present the radial, meridional, azimuthal components and the amplitude of the residual magnetic field in order to identify the component that 'best' fit (the radial component?) and 'worst' fit (the azimuthal component due to the poloidal nature of the field/lack of bend-back model?).

In conformity with the referee's comments, in the revised version Figures 5-7 showing the modelling results for the residual field now display cylindrical components in the JSM system together with the field magnitude. All of these figures have been significantly changed during revision.

In Figures 4 and 5 the observations at large radial distance exhibit large fluctuations. Do you have any explanation?. Does it make sense at all to include these data in the fit? Wouldn't it be better to smooth the data first? Also does Figure 4 (inbound) not suggest that RDC2 could be larger than 92RJ while in Figure 5 (outbound) RDC2 could be smaller than 92RJ ?

We believe the referee is referring to the radius of the outer boundary of the disc, R_{DC1}, in the above comments. As discussed in the paper, the field in the outer magnetosphere is strongly influenced by the variable and not well known conditions in the solar wind/IMF. For this reason we restricted our analysis of the dawn sector Juno data to the radial range less than 60 R_J where the relative influence of the solar wind is far less, and the field variations rather smooth. We do not include the fluctuating data at large radial distances into our fit.

In Section 4, I would recommend to carry out a valid and fair comparison with the CAN disc by actually fitting the four parameters of the CAN disc, otherwise the comparison seems arbitrary.

In response to this comment, we have now carried out a fair comparison of results using the CAN model to fit to the residual data, with results described in Sect 4 and Figure 7.

Figures could be made slightly bigger in general. In Figure 1 it might be useful to add panels for cylindrical and spherical distance as well as local time.

The figures have been made larger, and panels as suggested have been added to Figure 2 (was Figure 1).

Technical corrections

l. 27, p. 2: it would be nice to elaborate on why the IMF better off neglected rather than considering a typical value.

This issue is now discussed in more detail on page 5 lines 3–6. Basically, the added field would be small, of order the tail and magnetopause fields or smaller, highly variable with time on the scale of the Juno orbit, and of unknowable orientation. We thus conclude that it is justified to neglect this contribution on this basis, with the inclusion of the following text.

"For related reasons we also neglect the penetrating IMF term in equation (2), which is unknown when Juno is inside the magnetosphere, highly variable in direction with time, and typically of magnitude ~0.1-1 nT (Nichols et al., 2006, 2017). This field too, with penetration coefficient $k < 1$, is therefore similarly negligible in the $r < 60$ RJ middle magnetosphere studied here. "

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paragraph starting l. 12, p. 4: the discussion on the sensibility of S to the range of measurements considered for the fit is of prime importance. It needs some clarification and also expanded to justify the choice of range.

The choice of ranges for analysis of the Juno data now considered in the revised paper is fully explained on page 6 lines 12–14 and page 7 lines 1–7 (plus Table 1) as follows.

"With regard to the choice of interval employed to minimize *S*, we note that use of data from the innermost region is not optimal. The JRM09 internal planetary field model differs from observations at periapsis (1.06 RJ) by 0.3×10^5 nT (Connerney et al., 2018), which is reasonable accuracy for describing an observed field of magnitude $\sim8\times10^5$ nT, but does not allow us to distinguish the magnetodisc field of order 100 nT on this background. We thus restricted the inner border of the interval to consider $r > 5\ R_J$ only. However, on most passes examined here, the inner radial limit is set instead at somewhat larger radii by the data that are presently available for study. A further limitation on the region of calculation of *S* in the outer magnetosphere arises from the fact that the paraboloid model does not display regions of low field strength during intersections with the magnetodisc, as is observed in the field at larger distances, due to the use of the infinitely thin disc approximation (see Section 4). It is thus necessary to avoid these regions by also setting a maximum radial distance, R_{max}, on each pass (see Figure 2 for perijove 1)."

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l. 7, p. 5: what does the value S = 0.2 correspond to concretely in terms of statistics? As it stands it seems to be an arbitrary choice.

l. 14, p. 5: I am not sure to follow the argument. What is it meant by 'acceptable pairs of parameters are aligned with the line to some extent'? Some clarification needed.

Since the method of parameter optimization has now been changed as indicated above, and the corresponding text and figure omitted, these comments are no longer relevant to the revised paper.

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l. 1-5, p. 6: the discussion about the discrepancies observed in the internal field is too vague and lack content.

At page 6 lines 13-14 in the revised version we simply report factually on the accuracy with which the published JRM09 internal field model agrees with the published periapsis data on Juno PJ-01.

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paragraph starting l. 2, p. 7: as mentioned before does it really make sense to take arbitrary values for the CAN disc parameters. Wouldn't it make more sense to carry a proper fit?

As indicated above, a full fit and comparison with the CAN model is now presented in Figure 7.

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l. 7, p. 8: what do you mean by 'magnetodisc models with azimuthal current dependencies different from r−2 should also be investigated'? The CAN disc model just used in that Section varies as r−1. Do you have any suggestion? In Achilleos, Guio and Arridge (2010), it is suggested that the dependency is steeper than r−1.

According to our results the dependence is steeper than r^{-1}, but less steep than r^{-2}. Further analysis is the topic of on-going research.

Ivan A Pensionerov on behalf of the co-authors

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