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 #1

We are grateful to the Referee for their comments and attention to our work. 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

The paper adjusts the paraboloid Jovian magnetospheric magnetic field model from Alexeev & Belenkaya 2005 to magnetic field data recorded by Juno in the middle magnetosphere during its first perijove of august 2016. Two of the nine model parameters are constrained by the selected measurements (the magnetodisc inner radius R_DC2, and the magnetodisc field at its outer boundary B_DC), the other seven being fixed at their value deduced from the Ulysses flyby. The new values differ by resp. 14% and 26% from their Ulysses values, the error bars making the new R_DC2 value marginally consistent with the Ulysses one. The authors carefully discuss the selection of the 2 parameters to fit (while retaining the others at their Ulysses values) and the possible future improvements of the paraboloid model.

The referee correctly describes the content of the present work. However, we emphasize that the reasons for focusing on the selected model parameters while retaining others at the Ulysses values was carefully discussed and justified in the paper, as it is in the revised version. That is to say, in the dawn sector of the middle magnetosphere the role of the magnetodisc is predominant.

While the new values of B_DC and R_DC2 may be useful to colleagues working on the magnetosphere of Jupiter, I consider that a fit of 2 parameters from a single Juno perijove (out of 14 up to now) does not justify the publication of a regular article. With further work, there seems to be matter for a good regular article along two possible lines (not mutually exclusive): (1) analyzing many more Juno perijoves and studying the variability of the adjusted parameters, the fit quality, the possibility to constrain more parameters, to perform a global multi-perijove fit, etc. and/or (2) proceeding to some improvements of the paraboloid model (the most obvious one being to replace the infinitely thin disc by one of finite thickness) before applying it to Juno data. Accordingly, I request a major revision of the present manuscript.

In response to the referee's comment we have now enhanced the article by analysing data from the first ten Juno perijoves. All of them except PJ-01 lack the near-perijove data in a variable manner, which was the reason to choose to examine PJ-01 specifically in the original article. In addition, we also included all three magnetodisc parameters into the fit (inner and outer radius and field strength parameter), and, in response to comments from Referee 2, also improved the method of model parameter optimization to an automated non-linear optimization procedure (see responses to Referee 2). However, the results show that the best-fit model always has an outer radius at the maximum value set (95 R_J) by the model distance of the subsolar magnetopause. As indicated above, the reasons for employing the Ulysses values of the minor field contributions is fully discussed and justified. Overall, however, the article has been significantly revised, with Section 3 undergoing the most important changes. Concerning the comments on improving the paraboloid model, this is clearly outside the scope of the present paper, and is the subject of ongoing and future work. However, the present paper allows us to reveal the points which need improvement, specifically the thickness of the disc and variable dependence of the current density with radial distance.

Specific comments

The scientific interest for determining a new fit of some parameters of the paraboloid model is not discussed.

In response to this comment we have now inserted the following in the Introduction at page 2 lines 6-10, which we feel explains the significance of the study. "We note that the magnetodisc may be regarded as the most important source of magnetic field in Jupiter's magnetosphere, with a magnetic moment in the model derived by Alexeev and Belenkaya (2005) using Ulysses inbound data, for example, which is 2.6 times the planetary dipole moment. Consequently, the magnetodisc plays a major role in determining the size of the system in its interaction with the solar wind, and is thus an appropriate focus of study using Juno magnetic field data."

It is not clear if inbound and outbound passes are considered separately in the plots only (e.g. Figs 2, 4, 5), or also for the adjustment. In the latter case, it should be justified and the values found for the 2 legs compared.

The model parameters are the same for both legs of each orbit. In the revised paper the inbound and outbound passes are shown in the same figure to make this clear, and it is stated explicitly in the caption of Figure 5.

The covariance of B_DC and R_DC2 with the other 7 parameters could be better discussed. How are uncertainties likely to be affected ? Would this not imply that the present determinations of B_DC and R_DC2 are actually compatible with Ulysses data?

Evidently the fit results for the magnetodisc parameters could be significantly altered from those given in the paper if, e.g., the tail and magnetopause current parameters were varied through arbitrary ranges. However, as shown in Figures 3 and 4 the fields due to the tail and magnetopause currents in the Ulysses model are at least an order of magnitude less than the field due to the magnetodisc in the region inside 60 R_J considered in the paper, such that they will remain small in any plausibly modified model. This conclusion is reinforced by the fact, now noted in the related text, that the tail and magnetopause fields have opposite senses, and hence partly cancel. Brief examination then indicates that if these parameters are varied within plausible ranges, the disc parameters are altered by ~10%. For the purposes of the present paper we therefore believe it to be most satisfactory to compare disc parameters between Juno orbits while holding the minor contributing fields at constant and reasonable values.

For example, you state that "deep and sharp field decreases due to the equatorial current sheet encounters continue to be observed on the Juno trajectory even at large radial distances r > 90RJ". May this imply that the Ulysses value of the outer radius of the magnetodisk RDC1 = 92RJ is actually underestimated?

We believe the outer radius of the disk is not underestimated in the submitted or revised papers, for the following reason. We have to recognise that in the physical system near the dawn-dusk meridian and on the nightside the magnetodisc current sheet merges directly into the tail current sheet, so that at large distances it is the tail current sheet that is being observed. In the model, however, the magnetodisc is treated as axisymmetric, with a radius that for physical consistency must be limited to lie a least a little inside the subsolar magnetopause. The continuing current sheet on the nightside is then treated in the model as a separate current system as fully discussed in section 2, and now illustrated in Figure 1 in the revised article. We note that in the revised paper we also treated the outer magnetodisc radius as an adjustable parameter determined from a fit to the data as indicated above, but found that the best-fit value was always the largest value allowed by the above physical restriction, i.e., an outer radius of 95 R_J compared with a subsolar magnetopause radius of 100 R_J.

On p.8, you mention about the upstream solar wind "the limited information obtained by computer modelling using data from near Earth orbit as input". But there are today very good models of solar wind propagation to Jupiter and beyond (mSWiM model of Zieger & Hansen 2008, or the model from Tao et al. 2005).

Despite the acknowledged limitations of solar wind MHD modelling from Earth's orbit into the outer solar system (e.g., requirement for reasonable Earth-planet alignment, uncertainties in arrival time of a day or so, and inability to predict the north-south IMF component), the remarks in the submitted paper on this point were perhaps a little too negative. However, this discussion misses the main point about variability, since the solar wind will typically vary strongly on the time scale of the Juno passes, the overall orbit period being approximately two solar rotations. Such variability makes the task of modelling the field conditions in the outer magnetosphere very challenging, even if one has reasonable knowledge of the input conditions from MHD models. It is for this reason that we focus here on the dawn sector middle magnetosphere inside of ~60 R_J where, as we have indicated, conditions are not strongly influenced by the solar wind-related fields, but are instead dominated by the field of the magnetodisc (plus the planetary field). On page 4 lines 3–7 we have replaced the above comments by the following text, which we believe takes care of the referee's comments.

"In this paper we confine our attention to the middle magnetosphere, where, as we now show, the magnetic field is dominated by the magnetodisc and the planetary field. In the outer magnetosphere the field becomes strongly influenced by external conditions in the solar wind, and although in some circumstances these can be reasonably well predicted by MHD models initialised using data obtained near Earth's orbit (e.g. Tao et al., 2005; Zieger and Hansen, 2008), they will typically vary strongly on the time scale of the Juno orbit (Figure 2), and with them too the outer magnetospheric field."

Technical corrections

It may be worth saying in the title which part of the magnetosphere is studied (e.g. the magnetodisc) rather than mentioning only the data and the model.

In response to this comment we have now changed the title to "Magnetodisc modelling in Jupiter's magnetosphere using Juno magnetic field data and the paraboloid magnetic field model".

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p.1 l.11: flybys OF Jupiter ? (NB: this is only a suggestion, the native english-speaking co-author is certainly more knowledgeable than me about the style)

Changed as suggested (page 1 line 11).

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p.1 l.16: what do you mean by "angular model".

Now corrected to "plasma angular velocity model" (page 1 line 17).

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p.2 l.23: a sketch illustrating the 9 parameters would be useful.

In response to this comment we have added new Figure 1 in the revised version illustrating seven of the model parameters employed. Parameters k and B_{IMF} are not included in the analysis for reasons fully discussed in the paper, and are consequently not shown in the figure.

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p.3 l.11: maybe precise that "negligible" means here "<10% of».

In accordance with the referee's comment the text now specifies "less than 10%" (page 5 lines 2–3).

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p.3, l.15: explain why "the use of averaged parameters is not adequate in this region», i.e. address the solar wind driven variability.

This issue about solar wind and outer magnetosphere variability is fully dealt with above. This specific text is now omitted in the revised paper.

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p.4, l.19: rather than discarding the use of the root-mean-square absolute deviation because it depend strongly on the position of the inner fitting interval boundary, could another option be to use both it (to perhaps better constrain R_DC2) and the relative deviation (for B_DC and R_DC2) ?

This point is now discussed more fully in the revised version on page 6 lines 7-11. Use of the absolute deviation strongly emphasises the fit in the inner region where the residual fields are the largest. We regard the relative deviation as preferable since it equalizes the influence of the data from the whole interval employed, and gives a better fit to the data overall. A comparison of the fits for PJ-01 is shown in the figure attached below.

Caption of Fig. 4: the JRM09 model has not been subtracted from the residual magnetic field but from the observations.

The caption (now Figure 5) has been revised as follows.

"Observed (black) and modelled (red) residual fields in JSM cylindrical components, together with the residual field magnitude, for Juno perijove 1. The residual field is the observed field with the JRM09 internal field subtracted. The fields are plotted versus spherical radial distance with inbound data shown on the left and outbound data on the right. The same model field is used for both."

Ivan A Pensionerov on behalf of the co-authors

27 November 2018