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Modelling jovimagnetic secular variation: Results and implications

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Abstract

Taking a regularised minimum norm approach, two models of Jupiter's magnetic field have been created using all data collected by NASA within 12 R_J of the planet. The first model is time-averaged over the whole dataset, whilst the second permits linear time variation of the field. Comparison of these allow inferences to be made about jovimagnetic secular variation (JSV), with our favoured model indicating a $\sim 0.14\%$ yr^{-1} decrease in the dipole magnetic moment between 1973-2003. Further analysis suggests that this change cannot simply be attributed to an inadequacies of the System III 1965.0 reference frame.

1. Background and Methodology

There have been a number of attempts to model JSV but these have been inconclusive or ineffective for a number of reasons, including limited data usage, inadequate consideration of the magnetodisk field and the modelling approach taken. Here we attempt to resolve these issues by using all available data collected away from natural satellites and within 12 R_J of the planet, whilst establishing and removing the magnetodisk field for each individual orbit. We also take an alternative, regularised minimum norm approach to modelling the internal planetary field, following [1], thus permitting a higher resolution inversion.
(A more detailed methodology can be found in [2])

2. Results

Results are based on spherical harmonic degree 7 models which regularise the ohmic heat flow at the outer boundary of the dynamo generation region; from model analysis, we favour this to be located at 0.85 R_J, with a further linear drop off in conductivity to 0.90 R_J.

As can be seen in Figure 1, similar features appear in both models though some differences do appear between the geographic southern polar regions. This may be explained as the early missions account for the majority of data sampled in this area, and as a result has been assumed a temporal variation - demonstrating the limitations of this modelling approach.

Table 1 presents the accompanying dipole properties, with two previous Jovian field models from the literature for reference and comparison. Both the models calculated here and those previously display similar orientation; however those from this study posess lower dipole magnetic moments. It is apparent that this stems from the dominance of equatorial Galileo data.

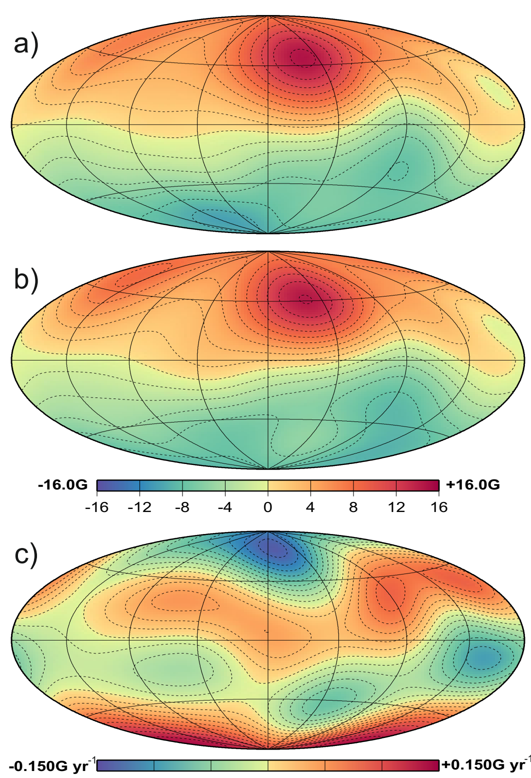

Figure 1: B_R at 1 atm pressure for time-averaged field model (a) and time varying field model (b). Field changes for time-varying model are seen in (c).

Model	**M** (G)	θ_M	λ_M
Time-averaged	4.1227	10.25	159.30
Time-varying	4.1281	10.25	159.82
O6 [3]	4.2760	9.45	159.91
VIP4 [4]	4.2637	9.51	159.23

Table 1: Dipole properties in R.H.S System III.

Inspection of Lowes power spectra plotted at the modelled dynamo generation region boundary for the time-varying model, shows flattening occuring between degrees 2-4, thus demonstrating a similarity with that of Earth's spectra when plotted at the outer core boundary.

Whilst the inferred JSV is dependant on the degree of spatial and temporal damping applied through regularisation, our favoured model suggests a decrease in the dipole magnetic moment of $\sim$ 0.136% per year, which translates to an overall decrease of $\sim$ 4% over the 30 year period.

3. Discussion

The suggestion has been made previously (e.g. [5]) that although modelling results may infer JSV, this may be a consequence of inadequacies in the System III 1965.0 reference frame. A common rotation angle in the time-varying model Gauss coefficients at the beginning and end of the period would strengthen this argument; however, this is not observed. Several further modelling enhancements have been used to further explore the problem, such as investigating the effect of data longitudinal coordinate adjustment by a magnitude relative to the time of observation since 1965; the model misfits and norms of these too favour JSV.

Whether true JSV has occured or reference frame error is reposible for the modelled changes, we propose that angular momentum exchange between the atmosphere and the planetary interior provides a viable mechanism for changes on the magnitude of those modelled. This hypothesis has been tested by considering changes in the zonal winds with time, using two velocity profiles compiled from data collected by Voyager in 1979 [6] and the Hubble Space Telescope in 1996 [7]. By applying the same principles as used in length of day studies for Earth, we conclude that even if the zonal winds exist in a simple spherical shell, penetrating just the upper 2% of the planet, the atmospheric velocity changes could translate to a 10° rotational offset of the interior over the same time period. Conversely, deep convection on cylinders tangential with the rotation axis would imply rotation of the magnetic field reference frame inconsistent with observations. Thus, we favour a shallow organisation of Jovian winds.

Jovimagnetic secular variation has further implications. [8] suggested a method to determine the depth of the dynamo region in Jupiter, proposing that the secular variation should be dominantly the result of magnetic advection in the dynamo region, rather than diffusion; therefore, at the depth of the top of the dynamo region the "frozen-flux" theorem would apply. This would imply conservation of unsigned flux $\int |B_r| d\Omega$. We examine the extent to which this relation is satisfied by our preferred model of secular variation and a range of other acceptable models to test this conjecture.

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