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Modelling jovimagnetic secular variation: A regularized minimum norm approach

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Abstract

Planetary dynamos, resulting from fluid flow in electrically conductive parts of their interior, are thought to be highly time dependent. Currently, our understanding of temporal variation of these fields is limited because we only have observations for one example - the Earth. To overcome this, data acquired by 5 NASA space missions between 1973-2003 are being used to investigate possible time variation of Jupiter's magnetic field.

Previous attempts to model jovimagnetic secular variation (JSV) 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. We attempt to resolve these issues here, by using all data avaliable within 12 R_J, establishing and removing the magnetodisk field for each individual orbit and taking an alternative, regularised minimum norm aproach to modelling the internal planetary field, thus permitting a higher resolution inversion.

1. Data

The accompanying table displays the data used. Notably, the majority were collected by Galileo predominantly in the equatorial plane, with the only close, high latitude pass of the planet being made by Pioneer 11. Data collected within close proximity of natural satellites has been excluded from analysis.

Mission	Year(s)	Number of orbits	Closest approach (R_J)
Pioneer 10	1973	1	2.8
Pioneer 11	1974	1	1.6
Voyager 2	1979	1	4.9
Ulysees	1992	1	6.3
Galileo	1995 - 2003	35	3.1

2. Methodology

The internal planetary magnetic field strength, $\mathbf{B}_I$, may be taken as the gradient of a scalar potential and then expanded in spherical harmonics,

$$\mathbf{B}_I = -\nabla\Psi$$

$$\Psi = a \sum_{l=1}^{\infty} \sum_{m=0}^{l} \left(\frac{a}{r}\right)^{l+1} \left[g_l^m \cos m\phi + h_l^m \sin m\phi\right] P_l^m(\cos\theta)$$

The magnitude of the Gauss coefficients, g_l^m and h_l^m define the field configuration; however, their determination is highly non-unique due to data used in the inversion being limited to spacecraft trajectories. In an attempt to remedy this, past studies have carried out low harmonic degree expansions and eliminated poorly resolved coefficients, consequently loosing small scale field structure. Here, an alternative regularised minimum norm approach is taken, following [1]. Models are sought which fit the data subject to a smoothing constraint,and thus with the minimum amount of detailed required. Small-scale field structure necessary to fit the data is expressed in the model.

However, the local magnetic field present at Jupiter, $\mathbf{B}$, may be considered as a combination of the $\mathbf{B}_I$ and the field generated external to the planet, $\mathbf{B}_E$. At Jupiter the primary component of $\mathbf{B}_E$ is from the magnetodisk field and to adequately model $\mathbf{B}_I$, this must be isolated and removed from the data.

This is achieved iteratively. The misfit between the O6 planetary field model [2] and an individual orbit of data is established and then used to calculate the external field using the the numerically recast formulation [3] of the magnetodisk model of *Connerney et al* (1981) [4]. The external field is then subtracted from the data and compiled with the similarly adjusted data from all other orbits, from which a new internal field model may be established and the process repeated until convergence is achieved.

This approach generates a field model, temporally averaged from all the data. JSV may be investigated by additionally parameterizing each Gauss coefficient by its mean value and a linear variation with time.

3. Analysis and enhancements

Whilst the fundemental approach has been outlined, the implication of several complementary modelling enhancements have also been investigated, in an attempt to better our understanding of data acquired by similar means.

Despite using all available data, the model is still compromised by the uneven data distribution. In particular, biases due to the dominant contribution from the Galileo orbiter must be avoided. Experience from modelling of the geomagnetic field suggests that in such cases, parameterisation of data uncertainty is of particular importance. By examining data residuals to our models, we investigate whether such parameterisation can improve our model of Jupiter. Residuals throughout the early modelling stages were observed, in part, to coincide with the the orientation of the disk field, suggesting incomplete removal of the external field contribution to the data. Thus error estimates appropriately larger in the direction of the estimated external field may allow the effects of this incomplete removal to be minimised.

Furthermore, fields arising from outer magnetospheric sources, such as the magnetopause, have been neglected thus far. Recent near-Earth geomagnetic models have parameterised these effects surprisingly effectively by a field uniform in both space and time. We investigate whether there is any evidence in the residuals for such a contribution, which might bias or alias into aspects of the field model.

Details of the results gained and their physical implications can be found in [5].

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