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Ocean-induced electric fields at Galilean moons

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Abstract

The effect of a possible ocean on Ganymede and Europa is predicted to induce a magnetic dipole as a result of the varying background magnetic field of Jupiter's magnetosphere (Zimmer et al., 2000; Khurana et al., 1997). The signature of such an ocean may have been detected by the Galileo magnetometer (Kivelson et al., 2002). By solving the diffusion equation in the ocean, and assuming Alfven wave propagation of these perturbations, we show that these induced ocean currents may produce a corresponding large-scale electric field, potentially detectable by the upcoming RPWI instrument aboard the JUICE satellite. We also present the magnetic field perturbations caused by an internal ocean.

1. Introduction

In the moons' frames of reference, the tilt in Jupiter's magnetic axis produces, via the planet's rotation, large variations in the background magnetic field. Smaller, but important, variations in the magnetic field are also caused by the moons' motions along their weakly eccentric orbits, which at times also cross the hinging Jovian current sheet.

We identify all magnetic field perturbations and their respective periods by fitting ellipses representing the moons' orbits through the current sheet model of Khurana et al. (1997) and background field model of Connerney et al. (1993).

The response from the ocean to these external field perturbations is investigated and modeled as a simple spherical layer with given thickness and conductivity. As per Schilling et al. (2004) and Zimmer et al. (2000) in their work on Europa, the response is a simple dipole field. Its amplitude varies for different values of conductivity and thickness, and the effect of these parameters on the large-scale electric field are studied.

2. Methodology

The electric fields are calculated directly from the induced dipole, and several simplifying assumptions must be made. The flow of plasma is ignored, hence there are no flow-specific structures: Alfven wings, upstream ram and downstream wake. Exospheric properties were set as per Galileo radio occultation and PWS measurement for the electron densities, assuming spherical symmetry – ions are assumed to be mainly O+ and O2+.

In this configuration, the time-varying magnetic dipole induces an electric field based on the propagation wave vector. As the wave timescale is much larger than the ionospheric current layer's diffusion timescale, the later has negligible effect on the magnetic field. Beyond this, perturbations propagate as Alfven waves in the background magnetic field.

3. Equations

Inside the ocean, the variable magnetic field produces an electric field as per Maxwell's equations. The large conductivity allows this electric field to produce a tangent current, shielding the background field (eq. 1). The perturbation arising from the ocean are assumed to propagate like Alfven/Magnetosonic waves, ignoring non-linear effects.

$$\sigma\mu_0\left(\frac{\partial\vec{B}}{\partial t}-\nabla\times(\vec{v}\times\vec{B})\right)=\nabla^2\vec{B} \qquad (1)$$

4. Summary and Conclusions

Under the above assumptions, an electric field of the order of a few mV/m may be present around both Europa and Ganymede.

For both cases, the likely scenarios of an earth-like ocean conductivity (~1-10 S/m) are investigated, in conjunction with ocean thicknesses of the order of 100km.

This field is stronger (~10 mV/m) when the moons are outside of the current sheet, when the ocean's response is weakest, and background ion density is low. Within the current sheet, the magnetic response is weaker and the electric fields are correspondingly lower (~1 mV/m).

While a linear approximation for the Alfven-waves is a bold assumption, we expect the orders of magnitude and their distribution over the surface to match our results. Further studies will include a 1D solution for the non-linear case, using the same exospheric properties.

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