Application of a Reconstruction Method for the Reconnection Rate to Cluster Data from the Earth Magnetotail

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Abstract

A theoretical model to describe the behavior of nightside flux transfer events (NFTEs) is applied to Cluster measurements from September 8^{th}, 2002, in the Earth magnetotail. The mathematical representation for the magnetic field and plasma flow time series is found in the form of convolution integrals by using the Cagniard-deHoop method. This representation allows to solve the ill–posed inverse problem in order to achieve the reconnection rate from the measured data. Methods to estimate the distance between the satellite and the reconnection site, as well as the Alfvén velocity are also presented. The reconnection rate is found to be in the range of 1-2 mV/m.

1 Introduction

In 1978, Russell and Elphic [1] found events in ISEE data which last some minutes and have a bipolar variation of the magnetic field component normal to the magnetopause together with a deflection of the tangential components. They interpreted this events as isolated tubes of magnetic flux and called them flux transfer events (FTEs). After the observation of these FTE signatures, several attempts were made to reconstruct different features of the reconnection process involved, e.g. [2, 3, 4]. Recently, Semenov et al. [5] developed a theoretical model to reconstruct the reconnection rate out of perturbations of the ambient magnetic field well outside the outflow region for an incompressible plasma.

In this work, we apply this method to so-called nightside flux transfer events (NFTEs). These are short-term events in the substorm-time plasma sheet, which can be described by impulsive variations of the reconnection rate in models of transient reconnection. Such structures noticed in the tail plasma sheet are often referred to as individual bursts of BBF, as transient

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plasma sheet expansions, as plasmoids or flux ropes, as well as NFTEs, e.g. [6, 7]. We reconstruct the reconnection rate from Cluster magnetic field measurements outside of the plasma sheet.

Our approach is based on the Cagniard-deHoop method [5], which we apply to an incompressible plasma for simplicity. From this method the magnetic field and velocity components are found to be convolution integrals of the reconnection rate. The reconstruction of the reconnection rate out of these components is therefore an ill-posed inverse problem, which we treat by using Tikhonov regularization [8].

2 The theoretical model

To calculate the magnetic field and flow components in form of time series, we use the Cagniard–deHoop method which gives the time series as a convolution integral in time. It is possible to find a solution for the displacement vector in Fourier–Laplace space from which the magnetic field and plasma flow parameters can be derived easily [5]. The Cagniard–deHoop method is used to perform the inverse Laplace transform analytically, leading to the z-component of the magnetic field in the upper half plane as

$$B_z(x,z,t) = C\,\Re \int_0^t g(x,z,t)\,E(t-\tau)d\tau\,, \tag{1}$$

where C is a constant, g is the integration kernel, which depends on the magnetic field configuration and the spacecraft position, and $E(t)$ is the reconnection electric field. For the other quantities similar expressions hold [5]. To handle the inverse problem, we take into account that satellite measurements are time series, therefore the magnetic field components are a function of time only, e.g. $B_z(x,z,t) = B_z(t)$. In such a case, the magnetic field in Laplace space is given as $B_z(p) = K(p)E(p)$. If we reconstruct the electric field in Laplace space, for large numbers of p, both functions are tending to zero, leading to large oscillations in the result. Therefore, we introduce a regularization operator $M(p)$, forcing the electric field to go to zero for large values of p, giving the reconstructed electric field in Laplace space as

$$E(p) = \frac{B_z(p)}{K(p)+M(p)}\,. \tag{2}$$

3 Reconstruction of the event on September 8^{th}, 2002

On September 8^{th}, 2002, an isolated substorm took place with an expansion phase starting at about 21:18 UT. Starting at 21:17 UT, a series of Earth–ward propagating 1 min–scale variations of the plasma environment in consistence with the picture of multiple NFTEs was observed (Fig. 1). The Cluster satellites were located at $[-16.7; 0.2; 4.5]$ R_e, which is clearly outside of the plasma sheet. Their measurements show the bipolar variation of B_z, a deflection of B_x, and a plasma flow directed to the plasma sheet (Fig. 1).

To apply our model, we need to know the distance between the satellite and the reconnection site. For the z–distance we us a magnetotail model [9], which gives a z–distance of about 3.5 R_e. The reconstruction of the x–distance was done by applying a global minimization routine revealing that the reconnection site was located at about 29 R_e tailwards. A characteristic velocity of the disturbances, which we assume to be in the same order as the Alfvén velocity, was estimated by using multipoint timing analysis [10] giving about 700 km/s. The reconstruction of the electric field is shown in Fig. 2. The reconnection electric field is found to be in the range of 1–2 mV/m, which is in good agreement with measurements of the tail electric field, e.g. [11].

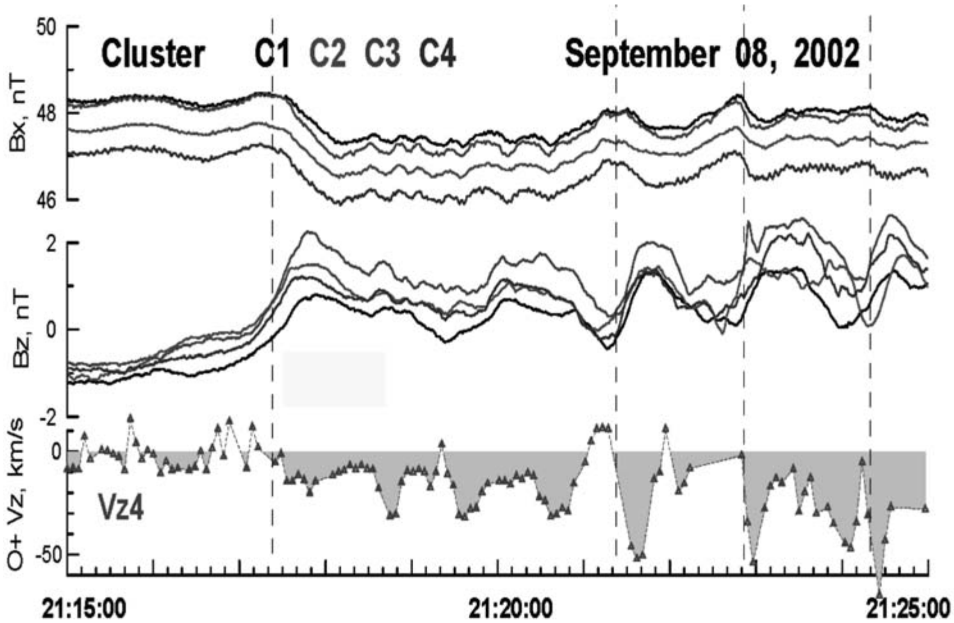

Figure 1: The event on September 8^{th}, 2002, observed by the four Cluster satellites. We analyze the NFTE starting at 21:21 UT.

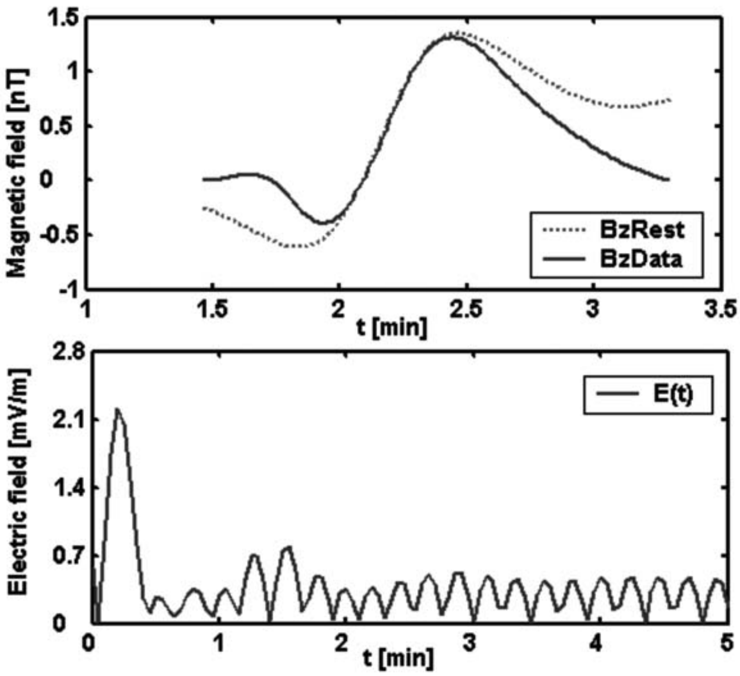

Figure 2: The reconnection electric field and the initial and reconstructed magnetic field.

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