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# Identification of full-substorm onset from ground-magnetometer data by singular value transformation

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Pi 2 magnetic pulsations are defined as impulsive hydromagnetic oscillations with a period of 40-150s. It is well-known that Pi 2 pulsations has one-to-one correspondence with auroral breakups (Jacobs et al., 1964; Saito, 1969; Li et al., 1998). Although Pi 2 pulsations have been accepted as a good indicator of auroral breakups, they correspond to not only full-substorm onsets but also most pseudobreakups. Hsu and MacPherron (2007) examined statistical properties of Pi 2 pulsations. They reported that the most probable number of Pi 2 bursts per substorm is 2. In the previous substorm researches, geophysical differences between pseudobreakups and full substorms have been studied. However, the physical difference in the magnetosphere and on the ground has not been clarified yet. In other words, to figure out the physical difference is a key subject for understanding the substorm onset mechanism. From this viewpoint, it is important to detect Pi 2 pulsations that correspond to full-substorm onset.

Another well-known substorm related phenomenon measured on the ground is positive bays. At the onset of the substorm expansion phase, the crosstail current is diverted down the magnetic filed lines. The current then flows in the ionosphere as the westward electrojet and returns to the tail along the magnetic field line. The perturbation of tail current can be represented by an equivalent eastward current, which completes the three- dimensional current wedge. The mid-latitude and low-latitude signature of this wedge is a positive perturbation in the north-south component. It is widely accepted that the sudden formation of the current wedge is essential to complete substorm onset. Hence, positive bays at mid and low latitudes could be an evidence for the occurrence of full substorms. From these arguments, we can say that Pi 2 pulsations accompanied by positive bays are one of the most reliable indicators of full-substorm onsets.

In order to identify full-substorm onsets from ground-magnetometer data, we propose a new algorithm to screen Pi 2 pulsations that accompanied by positive bays. As mentioned earlier, there are some works about automatic detections of Pi 2 pulsations. However, these methods are limited only to detecting wave packets. To screen Pi 2 pulsations that accompanied by positive bays, we should detect wave packets and changes of slopes simultaneously in ground-magnetometer data. Recently, singular spectrum analysis (SSA) has been used for change-point detections in time series (Moskvina and Zhigljavsky, 2003). Ide and Inoue (2005) developed the SSA-based change-point detection method, named singular spectrum transformations (SST), and showed that it was useful in knowledge discovery of causal relationships from a set of heterogeneous time series. Recently, the SST has been applied to determine the onset of positive bays (Tokunaga et al., 2010a, b). Unlike other conventional approaches, the SSA is data adaptive and does not employ any specific generative models. Further, SSA can extract simultaneously complex trends and periodic components. Hence, SSA-based change-point detection method likely fills our purpose, that is, to detect wave packets and changes of slopes simultaneously. In this paper, we introduce a new SSA-based change-point detection method, named Singular Value Transformation (SVT), to screen Pi 2 pulsations that accompanied by positive bays.

The outline of this paper is as follows. First, we describe the basic concept of SSA. Further, we introduce bay-score that provides information to determine whether the Pi 2 pulsation accompanied by the positive bay is present or not. Then, we define the framework of SVT. Next, we apply our algorithm to the ground-magnetometer data and compare the result with auroral images obtained by Polar Ultra Violet Imager (Polar/UVI). Furthermore, we evaluated the practical performance of the algorithm in a statistical study.

Keywords: substorm, positive bay, Pi 2 pulsations, SVT