Application of Empirical Mode Decomposition of cosmic ray in prediction of great geomagnetic storms

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Key Points:

- Great geomagnetic storms
- Empirical Mode Decomposition
- Cosmic ray
- Prediction

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Abstract

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1 Introduction

Geomagnetic storms are extreme space weather events that are generally thought to be caused by the interaction between the southward component of the interplanetary magnetic field in the solar wind and the earth's magnetosphere(Liu & Wan, 2014).Great geomagnetic storms(Kp$\geq$7) could affect satellites, aircrafts, VLF signal propagation and electric potential of power distribution network(Dorman, 2005; Starodubtsev et al., 2019; Liu & Wan, 2014). Meanwhile, great geomagnetic storms can also affect the ionosphere(Kravtsova & Sdobnov, 2016; Mandrikova et al., 2018) , magnetosphere(Manninen et al., 2008) and even hurt passengers on airplanes. Hence, the prediction before the sudden commencement of the great geomagnetic storms is very important to prevent these negative effect.

Cosmic rays observed on Earth's surface were modulated by Earth's magnetic, the inhomogeneous magnetic field of the sun and the solar wind(Mandrikova et al., 2018; Kravtsova & Sdobnov, 2016). Due to the influence of these factors, the features of the cosmic ray flux and anisotropy contain information about the disturbance of interplanetary space(Belov et al., 2003; Kichigin et al., 2017), which hidden in the recurrent and sporadic (mainly caused by coronal mass ejections(CMEs)) variation of cosmic ray. Through statistical analysis, Zhang et al. (2007) noted that most of Major Geomagnetic Storms (60%) , which occured between 1996 and 2005, were associated with a single CME at the sun, and 27 percent of Major Geomagnetic Storms were associated multiple CMEs. Shi et al. (2014) investigated all moderate and strong geomagnetic storms between 2007 and 2012, and obtained similar result. Therefore, extracting the disturbance information caused by CMEs from cosmic ray intensity observed on the Earth ground could predict great geomagnetic storms in advance.

Many authers have studied to predicted great geomagnetic storms by analyzing cosmic ray data (Dorman, 1999; Munakata et al., 2000; Kudela et al., 2001; Dorman, 2005; Xue, 2007; Zhu et al., 2015).Dorman (1999) presented that the great magnetic storms accompanied by cosmic ray Forbush-effects could be predicted by analyising cosmic ray data. Subsequent, Munakata et al. (2000)firstly systematically investigated cosmic ray precursors of geomagnetic storms. They statisticed and analyzed 14 major geomagnetic storm and 25 large geomagnetic storms observed from 1992 to 1998, and noted that cosmic ray precursors will appears 6   9 hours ahead to the large geomagnetic storms. Thought analysing online one-hour cosmic ray intensity, Dorman (2005) suggested that the Forbush-decrease in cosmic ray could be used for predicting strong geomagnetic storms 10 to 15 hours in advance. In forecasting practice, Xue (2007) used the deviation between the cosmic ray flux in 8h and the average flux in this period to reflect the cosmic ray fluctuations, and tested this algorithm with data of whole year 2001. The final indicated that the accuracy rate of this algorithm was 80% and the error rate was 20%. Zhu et al. (2015) employed morlet wavelet to extract the abnormal fluctuations of cosmic ray before great geomagnetic storms, and advanced the forecast of great geomagnetic storms caused by CMEs to more than 12h.

To extracting the sporadic variation from cosmic ray flux, we uesd Empriical Mode Decomposes (EMD) to analyze cosmic ray intensity of oulu station. EMD is a key part of Hilbert-Huang transform(Huang et al., 1998), which could decompose the nonstationary nonlinear signal into a finite set of intrinsic mod function (IMF) and a trend(Barnhart & Eichinger, 2011). Nonstationary nonlinear signal could be cearly divided into quasi-periodic oscillatory signal and suerimposed random background signal by using EMD(Kolotkov et al., 2016). EMD has been widely in sapce weather because of its powerfull ability of decomposition which is based on the local characteristc timescal of the data(Coughlin

& Tung, 2004; Barnhart & Eichinger, 2011; Käpylä, M. J. et al., 2016; Cho et al., 2016; Kolotkov et al., 2016; Stangalini et al., 2014; Xiang & Qu, 2016).

In the present paper, we use EMD to extract the random background signal of the cosmic ray intensity, which caused by CME. These random background signals contain the information about the disturbance of interplanetary space caused by CME, and will arrive the earth before CME.

2 Methodology

2.1 Overview

Cosmic ray(CR) contain a lot of information, about sunspots in the long run and diurnal variations in the short run.Shocks driven by energetic coronal mass ejections (CME's) and other interplanetary (IP) transients are mainly responsible for initiating large and intense geo- magnetic storms. Observational results indicate that ga- lactic cosmic rays (GR) coming from deep surface inte- ract with these abnormal solar and interplanetary condi- tions and suffer modulation effects. Most of the events are associated with transient decreases in cosmic ray intensity. Intense storms are having their well defined solar origin as during solar maximum the occurrence rate is 55% while it is only 45% during solar minimum phase of solar cycle.

Traditional signal processing methods can be devided into time-domain method and frequency-domain method. E

2.2 Empirical Module Decompisition and Ensemble Empirical Module Decompisition

EMD is a Vibration signals carrying a lot of information about the mechanical equipment health condition are frequently applied to monitor the machine health condition. The vibration signal decomposition is a critical step in machine health monitoring and fault diagnosis [1–3]. The methods to decompose vibration sensor signal mainly include FFT, wavelet transform, and EMD [4]. Among these methods, the FFT is one of the most widely used and well-established methods. However, there are some crucial restrictions on the use of Fourier transform. On the one hand, the FFT is a typical linear and stationary transform, which is not suitable for nonstationary signal analy- sis. On the other hand, it is suitable for global signal analysis instead of local signal analysis. Unfortunately, the vibration signals to be analyzed are often nonstationary and nonlinear especially under time-varying operational conditions. Hence, the FFT cannot fully fulfill the requirements of health monitoring and fault diagnosis. Recently, wavelet transform has become one of the most powerful signal processing tools on nonstationary signal decomposition [5–11]. Detailed descriptions of the existing research on application of the wavelet transform in machine condition monitoring and fault diagnostics are reviewed in Ref. [12]. In 1998, Huang et al. introduced the EMD method for analyzing data from nonstationary and nonlinear processes, which is based

2.3 Complete Ensemble Empirical Module Decompisition

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Enter acknowledgments, including your data availability statement, here.

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