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Solar Radio Emission as a Prediction Technique for Coronal Mass Ejections' Detection

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Abstract. In this report we present a possible scheme of short-term CME detection forecasting developed on the basis of statistical analysis of solar radio emission regularities prior to "isolated" solar Coronal Mass Ejections registered in 1998, 2003, 2009-2013.

Keywords. Sun: radio radiation, Sun: coronal mass ejections (CMEs), methods: data analysis

1. Introduction

It is generally accepted that solar activity is the driver of space weather. Space weather forecasting is an emerging science that is facing many tasks. Some of them are the definition, classification and representation of solar features, and the establishing an accurate correlation between the occurrence of solar activities (e.g., solar flares and coronal mass ejections (CMEs)) and solar features observed in various wavelengths. The concept of CME as a global phenomenon of solar activity caused by magnetohydrodynamic processes is generally accepted. These processes occur in different wavelength ranges of emission and manifest in the microwave emission. The usage of radio-astronomical data for CME prediction is convenient and promising. It is so because the majority of the proceeding processes, as a rule, is reflected in the radio emission; spectral measurements cover all heights of solar atmosphere, and sensitivity and accuracy of measurements make it possible to record even small energy changes.

It should be noted that for the development of a prediction technique 2 ways of using the experimental data are possible: a) to be based on the totality of all available data, obtained by different methods, different tools, including of those not intended for the solution of the problems of forecast; b) the use of data obtained by one apparatus, and with uniform procedure. We use the first way and present several facts to be the basis of CME prediction during different time intervals.

2. Overview

We have used the data of solar microwave emission obtained by ground based round-the-clock monitoring of solar radio emission (data of the worldwide network of solar observatories in the radio-frequency band). Our examined set of CMEs consists of "isolated" CMEs: the time-nearest Coronal Mass Ejections are not recorded for least 8 h before and 6 h after the considered event. Selection of "isolated" CMEs is related with the ability to identify uniquely the registered radio emission with the sources of formed CMEs. We also use the data of X-ray and Hα flares location on the solar disk to determine possible sources of radio precursors of Coronal Mass Ejections.

Obviously, phenomena in the radio range that precede powerful energy releases, primarily, Coronal Mass Ejections, should be observed during different time intervals: from

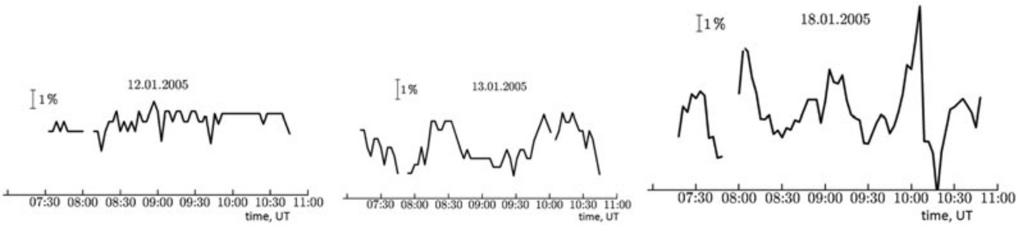

Figure 1. Dynamics of the radio emission flux during the January 2005 extreme events at the frequency $f = 9\,114$ MHz according to the RAS NIRFI "Zimenki" data.

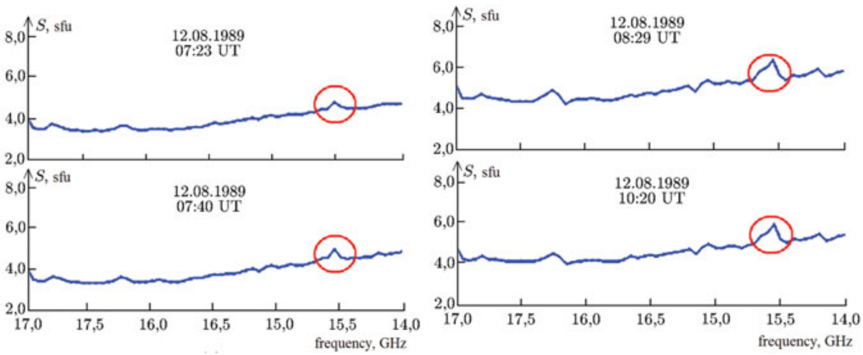

Figure 2. Radio emission spectra of active region on August 12, 1989 (NOAA/USAF 5638) at fixed times before CME's detection on coronagraph (12:59 UT) according to the sweeping spectrograph data (1 spectrum / sec, 100 MHz spectral resolution).

several days (which is typical for the evolution of the active region as a whole, and development of solar activity centers and complexes) to several hours and tens of minutes.

The study of the evolution of radio emission flux in the centimeter range showed that a few days before CME's detection, an increase in the amplitude of long-period ($T \geqslant 20$ min) pulsations of radio flux was observed (Fridman & Sheiner 2009).

This effect being observed before solar extreme events on January, 2005 (15/01/2005, 06:30:05 UT; 19/01/2005, 08:29:39 UT) is illustrated below (Figure 1). As can be seen from the figure, before the Coronal Mass Ejection's detection on January 15, 2005, the amplitude of long-period pulsations increased, on January 13, 2005, compared with January, 12. On January 18, 2005, the pulsation amplitude also increased in the day before the CME's detection on January, 19. After the events, the observed oscillations are at the level of the noise characteristics of the equipment used.

At closer times, before the detection of Coronal Mass Ejections at the coronagraph, a steady narrow-band spectral structure is detected in the intensity of microwave radio emission, 5-8 hours prior to the event. For example, approximately 5 hours before the CME's detection on August 12, 1989, one can see very small spectral features on the right side of spectra (Figure 2). The closer the time of CME detection the larger the amplitude of the feature is. The value of its flux is about 1 sfu and the spectral interval varies in 200-400 MHz just 1.5 hours before CME's detection. According to our ideas, the formation of this special feature is the reflection of reconstruction of the structure of the active region. Its stability is explained by the large three-dimensional scale of the phenomenon.

The third observed phenomena, preceding the appearance of a CME, are the presence of microwave precursors in the two-hour interval prior to CME's detection (Sheiner & Durasova 1994, Sheiner & Fridman 2010). This two-hour interval is especially important

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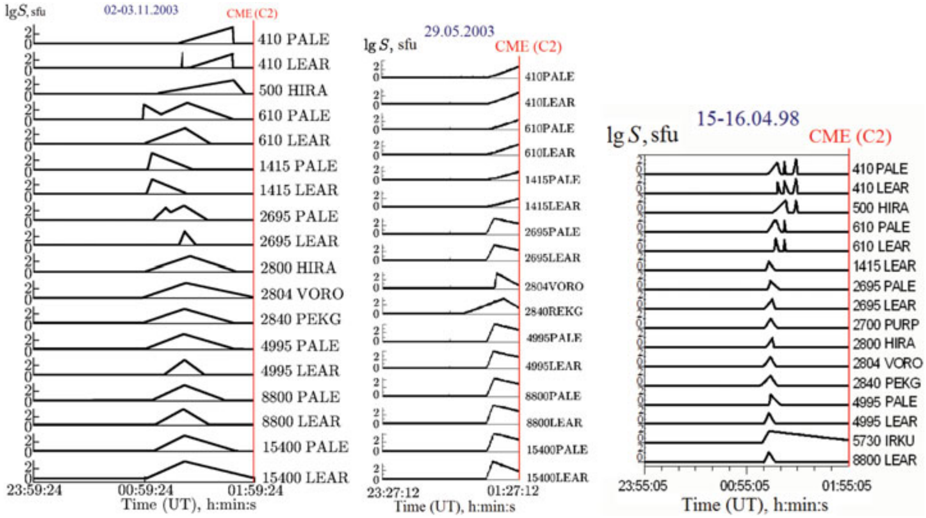

Figure 3. Schematic time profiles of microwave precursors. Left Y-axis is the observed flux on a logarithmic scale (in sfu). Right Y-axis (in red) is the moment of CME's detection on coronagraph LASCO, indication of the frequencies of the observations and abbreviations of observatories itself.

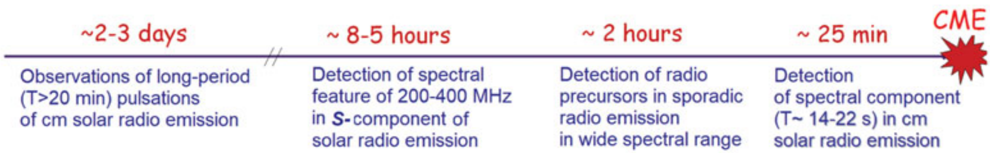

Figure 4. Preliminary qualitative forecasting scheme.

in studies, because it clearly exceeds the estimated propagation time of CMEs from the surface to the coronagraph FOV. It covers the period of the direct formation of CMEs, their separation and initial propagation in the lower corona of the Sun. These phenomena are illustrated in Figure 3. In the time interval of about 25 minutes before the Coronal Mass Ejections' detection periodic oscillations of the intensity of solar microwave emission are observed, with the periods of 14-22 seconds at wavelengths 3 and 10 cm. Moreover after the passage of the CME at the heights of the solar atmosphere where radio emission at these wavelengths is formed, such fluctuations on $\lambda = 3$ cm disappeared, and they were weakened considerably on $\lambda = 10$ cm. It is worthwhile to note that in several cases, when observed radiobursts were not connected with CMEs, periodic oscillations of intensity with these periods were not observed in the time intervals indicated.

The proposed way of short-term forecast of CMEs is based on the analysis of time and spectral data of solar microwave emission in the period preceding the phenomenon of CME (Figure 4).

Hereby it is possible to use the data of solar radio emission monitoring belonging to the Solar Data Service, for analysis and developing a procedure for short-term and very short-term CME forecasting.

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