Correlating Type II and III Radio Bursts with Solar Energetic Particle Events

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Introduction

Only some coronal mass ejections (CMEs) result in a shock wave through the corona, and few of these shock waves accelerate solar energetic particles (SEPs) towards Earth. This study examines several variables (right) that may be connected to the occurrence of SEPs in an effort to determine what factors are most important in distinguishing which shock waves will result in SEP acceleration toward Earth. 123 Type II radio bursts (Jan. 2010-May 2013, NASA Wind-Waves) were examined along with 24 SEP events (NOAA SWPC), 22 of which were associated with a Type II radio burst.

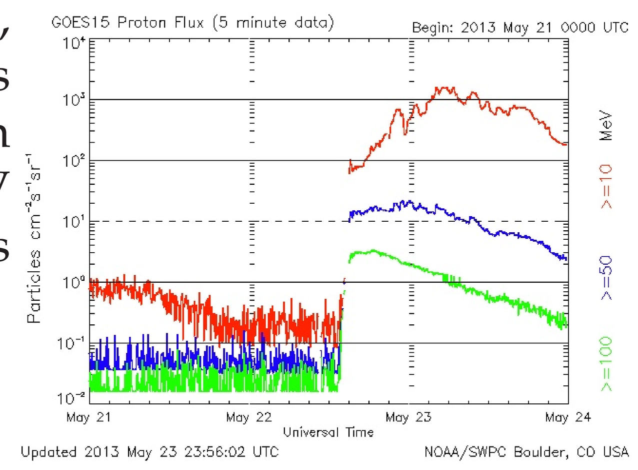
Variables Collected

Type II Radio Bursts	Type III Radio Bursts	X-ray Flares	Langmuir Waves	SEPs
Duration	Duration at 1MHz	Peak Intensity	Peak Intensity	Increase Time
Frequency Range	Slope	Duration		Peak Time
Slope	Integral Intensity			Peak Intensity
Peak Intensity				
Integral Intensity				

The radio and SEP properties from all Type II bursts in the NASA Wind-Waves catalog, Jan 2010-May 2013, were examined. Of these 123 bursts, 94 were detected with NASA Wind/WAVES.

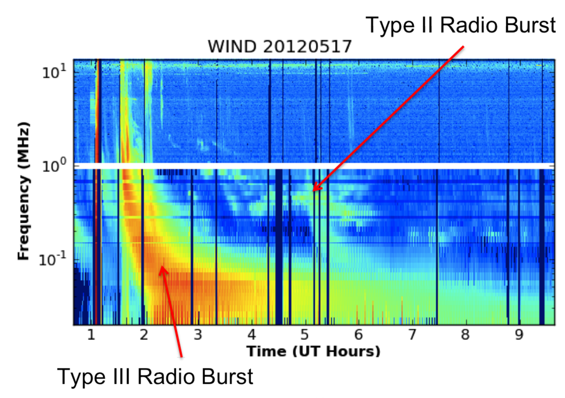
Solar Energetic Particles

SEPs are high-energy particles, such as protons, which are accelerated at the Sun and speed outward into the solar system. If they reach Earth, they can be harmful to satellites, communication systems, and humans in space or on polar airline routes. NOAA defines an SEP event as an occasion when the flux of protons with energies higher than 10 MeV exceeds 10 pfu (particle flux units) as measured by the GOES satellites in geosynchronous orbit.



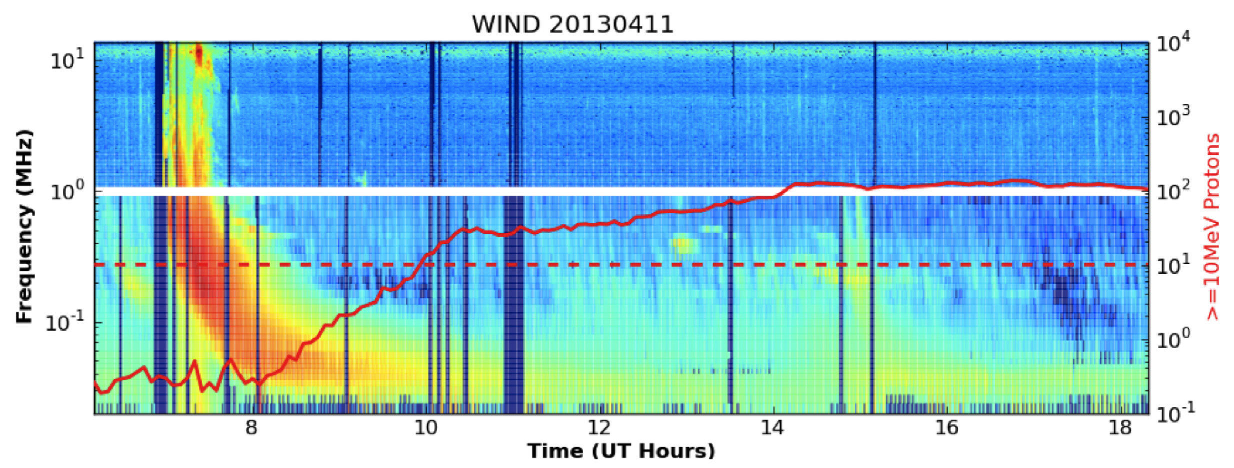
Right: Proton flux recorded by GOES during an SEP event.

Radio Bursts



Left: Radio data from the RAD1 and RAD2 radio receivers on the WIND satellite, showing a Type II and a Type III radio burst.

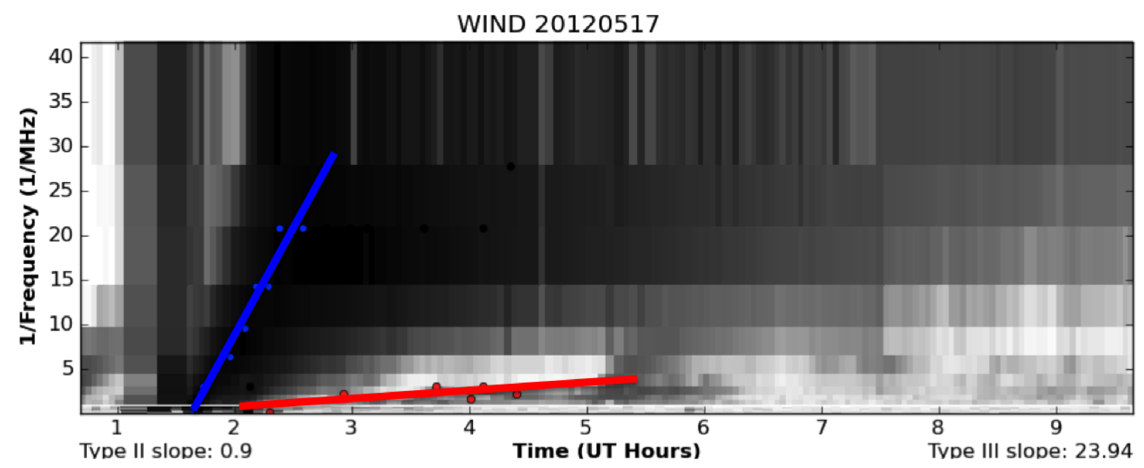
The most intense SEP events are associated with shocks, driven by CMEs, which accelerate particles as they move through the corona. These shock waves accelerate electrons, which then emit radiation at the local plasma frequency. This radiation appears as a Type II radio burst (above). 22 of the 24 SEP events studied were "gradual" SEP events associated with one of these Type II radio bursts. These "gradual" SEP events have higher fluxes and longer durations than "impulsive" SEP events, which are not associated with coronal shock waves. All the observed Type II bursts that were associated with SEP events also appeared in conjunction with a Type III radio burst, which are thought to result from magnetic reconnection over the active region.



Above: Connection between Type II and III radio bursts (background) and solar proton flux from GOES (red).

Radio Properties

The frequency drift of Type II radio bursts is related to the speed of the shock that created them. This was parameterized as the slope of the burst in 1/f space, in which the bursts are almost linear (Lobzin 2010). By transforming the frequency axis to 1/frequency, removing gaps, boxcar smoothing, and increasing contrast via histogram equalization, it was possible to pick out points (local maxima) and fit lines to determine the slope of the bursts.



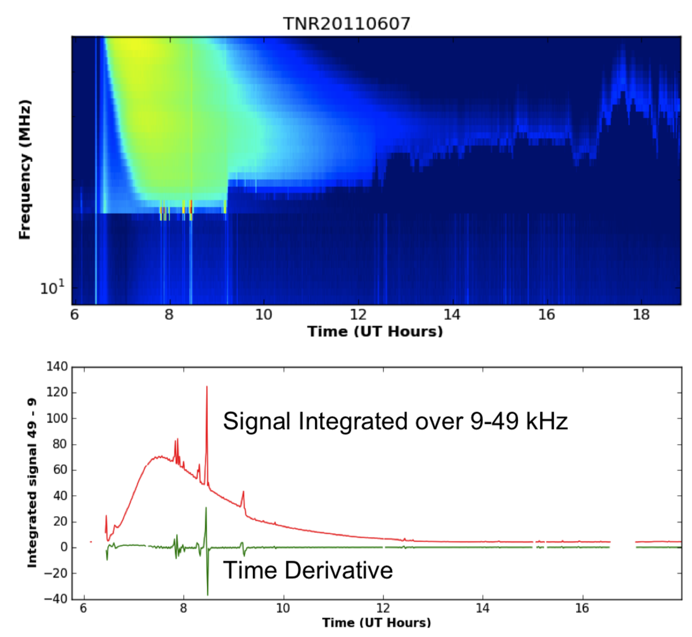
The intensity of Type III bursts was determined by integrating along the previously determined line of best fit from high to low frequency until log(intensity)<15% of log(maximum).

The intensity of Type II bursts was harder to quantify, since they are less consistent and never continuous. Two parameters were extracted: the single-point maximum along the line of best fit, and the integral from that maximum point along the line until intensity decreased by 15% from the maximum.

MacDowall (2003) defined the duration of a Type III burst as the number of minutes for which the signal at 1MHz exceeds 6dB (four times the background value). This duration was used as another parameter to characterize Type III bursts.

Local Langmuir Waves

Electrons accelerated by the shock wave sometimes pass by the WIND satellite, causing Langmuir waves visible at the local plasma frequency. When these local Langmuir waves are present, it is a good indicator that the active site accelerating the electrons, and presumably the SEPs, is magnetically well-connected with the Earth. The maximum intensity of these waves was used as another variable in the final analysis.



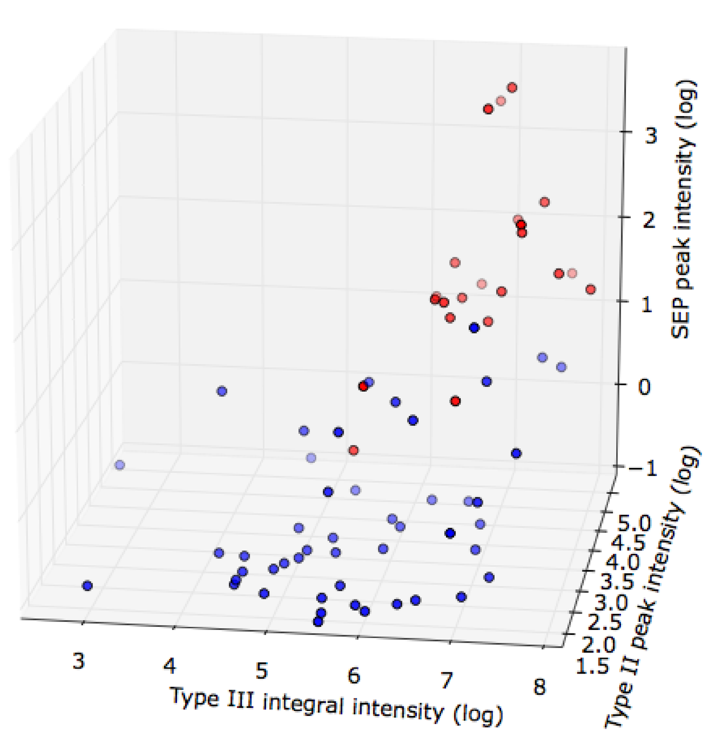
Left: The lower edge of Type III bursts can appear at the same frequencies as Langmuir waves. By determining the presence of Langmuir waves by the time derivative of the signal integrated over frequencies of 9-49 kHz, these gradual Type III peaks can be ignored.

X-Ray Flares

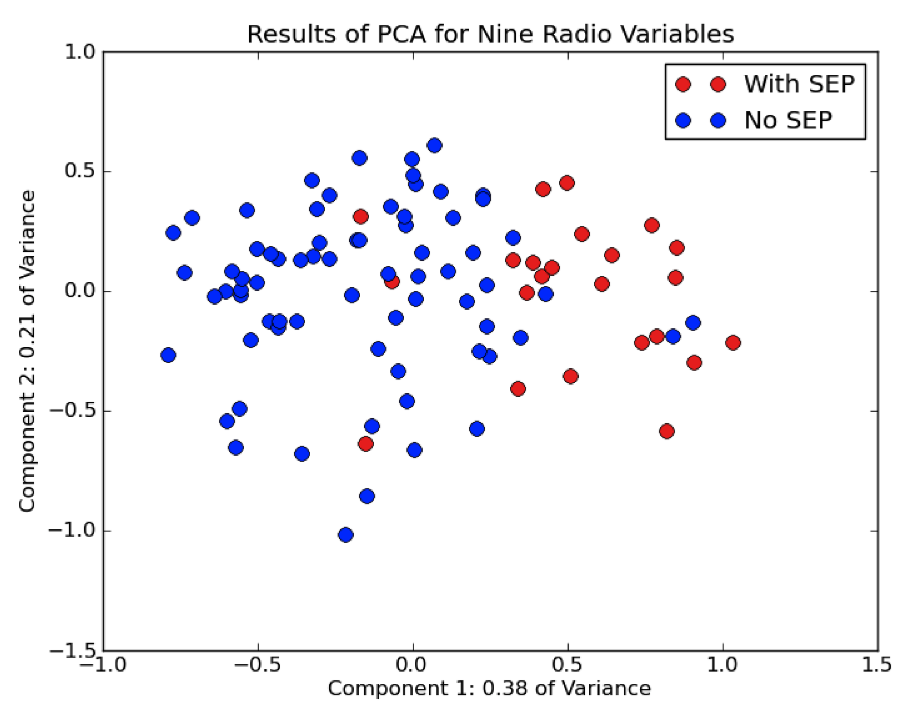
X-ray flares are also often associated with solar activity resulting in SEPs. X-ray flares occurring within 2 hours of the onset of the Type II burst were considered relevant, and the maximum peak flux and duration were used as additional variables for data points from January 2010-November 2012.

Principal Component Analysis

When PCA was performed, using the scikit-learn Python library, on the six Intensity variables, it was found that all the intensities were correlated (with weights over 0.3) except for X-ray peak intensity. However, because the X-ray data was not complete, the X-ray result is not significant. Overall, the intensities of radio phenomena were correlated with the intensity of SEPs, as shown below.



When PCA was performed on all nine variables extracted from radio data, it was found that the first component was able to separate most SEP events from non-SEP events. A simple threshold will identify 19 of the 22 SEP events with only 5 false alarms. The main variables that load on this component, with weights over 0.3, are Type III Integral Intensity, Type III Duration, Type II Peak Intensity, and Langmuir Peak Intensity.



Conclusions and Future Work

From a thorough analysis of the radio properties of SEP events from 2010-present, we find that the intensity of Type II and III bursts and Langmuir waves, as well as the duration of Type III bursts, are well-correlated. Our PCA shows that using these variables alone, SEP and non-SEP events are clearly separable. Therefore, the radio properties are a potentially important diagnostic for predicting SEP events. We plan to extend this investigation by analyzing STEREO/WAVES data over the same period. As STEREO is the only space-based radio mission with real-time data, our aim is to ultimately use the STEREO beacon data to predict SEP events in real-time.

Acknowledgements and Citations

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NASA Wind-Waves. Type II and IV Burst Lists. http://www-lep.gsfc.nasa.gov/waves/data_products.html.

NOAA SWPC. Solar Proton Events Affecting the Earth Environment. http://www.swpc.noaa.gov/ftpdir/indices/SPE.txt.