As we increasingly depend on satellite technology in our everyday lives, understanding space weather is of critical importance to our national interests. Magnetic storms in the Earth’s space environment often occur following periods of intense solar activity. Some, but not all, of these storms are accompanied by a rapid enhancement in the population of very energetic electrons that travel at near-relativistic speeds. These so-called “killer electrons” are of particular interest to the space science community because of their potential threat to spacecraft instrumentation. Recent work has indicated that the mechanism for the production of these relativistic electrons is likely to be associated with pulsations in the Earth’s magnetic field at ultra-low frequencies (ULF).

Figure 1. A cross-section of the Earth’s magnetosphere and the solar wind that impacts it.

In this study, the dynamic power spectra of ULF waves over a frequency range that encompasses three classes (Pc3, Pc4, and Pc5) of these waves are examined for two major magnetic storms: one with, and the other without, relativistic electron enhancement. The ULF fingerprint of the storm that is accompanied by the energetic electrons exhibits a significant and prolonged increase in wave power during the storm’s recovery phase over a frequency range that encompasses all three wave classes. Alternately, the fingerprint of the storm without the energetic electrons shows an increase in wave power only for the lowest frequency waves in the Pc3 band. This difference indicates that a prolonged, broadband enhancement in wave power may be necessary for the production of killer electrons.

Motivating Questions

While research on the ULF power-relativistic electrons connection during magnetic storms has led to a variety of significant and interesting results, there are topics that merit further investigation. Some examples include:

- Do ULF waves play a significant role in generating the large increases in the energetic-electron population seen in some storms?
- If ULF waves are truly part of the generation mechanism, what special characteristics, if any, must they have?
- Can magnetic storms be fingerprinted using ULF wave power?

Methodology

- Storms were identified by a characteristic signature in the Dst index, a measure of the Earth’s magnetic field. A magnetic storm typically exhibits a sudden rise in the Dst index at its commencement, then a drastic drop to a minimum value and a recovery over several days to normal conditions.
- For the period from 1984 to 1988, we have compiled a database of 65 storms along with corresponding magnetic field and energetic electron data. For this preliminary study, we investigate two storms from the database, one with and one without an increase in the population of energetic electrons.
- For each storm, the ULF dynamic power spectra over a continuous frequency range containing all three ULF wave classes (Pc3, Pc4, and Pc5) are calculated from the magnetic field data. The results are shown in Figure 2.
- A more quantitative view of the ULF fingerprint can be produced by a comparison of the actual values of the wave power during the storms. This is illustrated in Figure 3.

Analysis and Results

Figure 2. Two magnetic storms, one with, and the other without an increase in the energetic electron population.

- The dynamic power spectrum of the ULF waves is significantly higher across the entire frequency range (0 - 50 mHz) for the storm where the electrons are energized. Since this range encompasses all three types of ULF waves, it appears that a broadband increase in wave power may be necessary for the production of killer electrons.
- The yellow box in the bottom panel of each figure marks the days during the storm recovery phase when the energetic electron population greatly increases (top storm) or shows no change (bottom storm). Note that the ULF wave power at lower frequencies remains high for the storm with the killer electrons, but not for the other storm.

Figure 3. A comparison of ULF wave power between the two storms. Day 0 is when minimum Dst of the storms occurs.

- An alternative view of wave power during the two storms is presented in Figure 3, which depicts a comparison of power values for the three ULF wave classes, Pc3, Pc4, and Pc5. The red line represents wave power for the storm with energetic electrons (top storm of Figure 2), and the blue line for the storm without (bottom storm of Figure 2).
- We note that during the storm recovery phase (the yellow region), the wave power remains at a higher level for the storm with the energetic electrons. This period corresponds to the highlighted interval of Figure 2 during which the energetic electron population is increasing.
- This observation indicates that a prolonged increase in ULF wave power may be necessary for the production of energetic electrons.

Conclusions and Future Work

By comparing two magnetic storms, we have found that ULF wave power may play a significant role in the enhancement of energetic electrons populations during the storm recovery phase. Possible requirements for the energetic electron increase are:

- The power increase is broadband rather than limited to a narrow range of ULF frequencies.
- The power increase is prolonged during the recovery phase, particularly for Pc5 waves.

Using our large database of magnetic storms, we will extend this research by producing a statistical fingerprint of each of the two storm types. Statistical differences observed in the fingerprints will provide compelling evidence that ULF waves are indeed a critical component of the mechanism responsible for the appearance of energetic electrons.

Acknowledgments

This research is supported by the National Science Foundation award ATM-0638845 (Dr. Kile B. Baker, Program Officer).