INTRODUCTION

Shocks in the solar wind can be useful precursors to the onset of magnetic storms. The measurements made on board the NASA ACE spacecraft, located at the L1 point, enables the detection of a shock in the solar wind 20 minutes after it crosses the magnetopause. When detected at ground level by magnetometers located at magnetic observatories these are classified either as a Storm Sudden Commencement (SSC) or a Sudden Impulse (SI). A shock implies an abrupt change in the solar wind characteristics. The most important data for detecting the shock are the bulk speed (kms⁻¹), the density (particles/cc) and the magnetic field strength (nT). An example of a solar wind shock transition is given in Figure 1. Certain shock characteristics such as the sign of each of the steps in the data types, can help classify the shocks as shocklets (low speed drops followed by high speed increases) or as shocks (large drops followed by large increases). We have developed two detection shock algorithms, which attempt to detect and classify shocks using ACE real time data.

DETECTION BY WAVELET ANALYSIS

Figure 1 suggests a simple step function would be a useful first approximation model. We are trying to detect, classify and scale the shocks using a multi-scale edge detector based on the wavelet transform. The edge detector is simply a multi-scale version of the first derivative of a Gaussian function. For near real time (5 minute) operation the first three scales of the transform are used in order to minimize the end effects in the data segment. Shocks, of a peak are obviously declared if the cross-scale product in each of the appropriate variables exceeds pre-set thresholds. Preliminary thresholds were chosen by reference to a sub-set from two published shock lists [4,5].

DETECTION BY THRESHOLD METHODS

This shock detector works by computing the change in each of the solar wind parameters and dividing by their most recent standard deviations. If this ratio is bigger than 3 then a shock is declared. This shock detector monitors in operation: the High Q method, which simply uses the magnetic field strength. The Low Q method tests for significant changes in solar wind velocity, density, and magnetic field strength and the component of velocity normal to the shock front [1,6], and the Low Q method, which simply uses the magnetic field strength. The Low Q method has been found useful during high energy events when the ACE shock detector was not able to detect shocklets (low speed drops followed by high speed increases) or as shocks (large drops followed by large increases). The optimum POD and the probability of a false detection (POFD). The operating characteristic (ROC) for the Low Q method. The ROC shows these data as a function of threshold. The axes of the ROC are the probability of detection (POD) and the probability of a false detection (POFD). The threshold levels decreases from left to right in the graph and shows how we can use this graph to determine the optimum threshold for the Low Q method. A high POD would be acceptable to most users. We have chosen a compromise that produces low POFD and is sensitive to shocklets. The optimum threshold for the High Q method has been defined as the intersection of the High Q and Wavelet methods in a similar way to that of the Low Q. The results of this study suggest some changes to the simple threshold algorithm may be desirable. The High Q method would be improved by lowering some of the pre-set thresholds, which may improve the POD and lower the number of false detections. The threshold levels for the High Q method have been chosen to detect, classify and scale these events. An accurate method can be found if it would significantly reduce the time taken for this task and remove the subjectivity that exists in the manual method. In an initial study we have compared the four methods of detecting solar wind shocks (2000 to 2004) identified by ISGI, High Q, Low Q and Wavelets with lists of lists of random shocks. Both the ISGI collated list of SSCs and the list of those identified from one of the seven UK observatories are compared. The results are shown in Table 2. The High percentage of correct SSC predictions for the High Q shock list provides independent evidence that the ROC threshold used here is a suitable method. The center of this shock detector is calculated from real measurements from the SOHO spacecraft, and checked for consistency with the magnetic field behaviour from ACE or WIND spacecrafts. We have then modified this original list by removing those that were not clear shocks and including new shocks that were detected by eye in the ACE spacecraft data. Although we consider this the best available for comparison, it is not a definitive list of shocks and the accuracy results shown here should be considered relative rather than absolute.

Rapid variations

For many SSCs, like the example shown in Figure 4, and SIs recorded at magnetic observatories, have been manually classified and scaled by observers around the world according to the definitions given in [7] and supplemented in [8]. In these events the solar wind shock arrival at the magnetosphere are recorded almost simultaneously around the world. Automated methods of shock detection being developed could be useful in communicating with users in order to detect, classify and scale these events. As an example we could find it would significantly reduce the time taken for this task and remove the subjectivity that exists in the manual method. The ROC shows these data as a function of threshold. The axes of the ROC are the probability of detection (POD) and the probability of a false detection (POFD). The threshold levels decreases from left to right in the graph and shows how we can use this graph to determine the optimum threshold for the Low Q method. A high POD would be acceptable to most users. We have chosen a compromise that produces low POFD and is sensitive to shocklets. The optimum threshold for the High Q method has been defined as the intersection of the High Q and Wavelet methods in a similar way to that of the Low Q. The results of this study suggest some changes to the simple threshold algorithm may be desirable. The High Q method would be improved by lowering some of the pre-set thresholds, which may improve the POD and lower the number of false detections. The threshold levels for the High Q method have been chosen to detect, classify and scale these events. An accurate method can be found if it would significantly reduce the time taken for this task and remove the subjectivity that exists in the manual method. The ROC shows these data as a function of threshold. The axes of the ROC are the probability of detection (POD) and the probability of a false detection (POFD). The threshold levels decreases from left to right in the graph and shows how we can use this graph to determine the optimum threshold for the Low Q method. A high POD would be acceptable to most users. We have chosen a compromise that produces low POFD and is sensitive to shocklets. The optimum threshold for the High Q method has been defined as the intersection of the High Q and Wavelet methods in a similar way to that of the Low Q.

SHOCK DETECTION ACCURACY

In order to test the accuracy of the detection methods an independent reference list of shocks has been compiled. We have used the shock event lists from [2,4,5]. These were originally subjectively identified by eye, using ACE level 2 data, which were then subsequently reviewed and checked for consistency with the magnetic field behaviour from ACE or WIND spacecrafts. We have then modified this original list by removing those that were not clear shocks and including new shocks that were detected by eye in the ACE spacecraft data. Although we consider this the best available for comparison, it is not a definitive list of shocks and the accuracy results shown here should be considered relative rather than absolute.

Table 1: Accuracy of the shock detection methods as compared to a prepared check list of shocks

<table>
<thead>
<tr>
<th>Method</th>
<th>Number of SSCs</th>
<th>Detected Shocks</th>
<th>Detected SS/Cs</th>
<th>POFD (%)</th>
<th>POD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISGI</td>
<td>338</td>
<td>305</td>
<td>90.8</td>
<td>1.9</td>
<td>96.4</td>
</tr>
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<td>238</td>
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A practical application of this shock detection is that it can provide power companies with advanced warning of the potential for geomagnetically induced currents. The automatically detected shocks have been compared with the reference list over a 5 year period (2000 to 2004) and the results are shown in Table 1. Although the operational detection algorithms use real time ACE data, which are of lower accuracy results shown here should be considered relative rather than absolute.

Table 2: The percentage of shocks that are followed by SSCs. Two lists of High Q are used in the comparison: the ISGI collated list and the list of SIs or SSCs that have been identified as A or B class [8] from at least one of the seven UK observatories.

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The usefulness of automated detection of solar wind shocks for this task is examined by testing these against lists of identified SSC and SI events.

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- ISGI and Ebro Observatory for the collation and provision of rapid variation data.
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REFERENCES

[7] IAGA 2005 Scientific Assembly, Toulouse, France, Session GA02/0, Poster C29