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CLASSIFICATION OF ABRUPT CHANGES OF THE INTERPLANETARY MEDIUM PARAMETERS BY THE METHOD OF ARTIFICIAL NEURAL NETWORKS

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Abstract. The technique of differentiation of discontinuities in the registered plasma and magnetic field parameters on SC WIND in 1996-1999 into classes adequate to the known types of magnetohydrodynamic discontinuities is developed. The classification with the help of designed artificial neural network (ANN) of «Cohonen layer» type is accomplished. We have found 12 contact and 20 tangential discontinuities, 30 fast and 20 slow shock waves. An algorithm for determination of orientation of discontinuities' surfaces by one-dimensional observation of jumps of solar wind parameters on board a spacecraft is proposed.

1. Introduction

Different types of jumps, or so-called discontinuities in parameters (shock waves, tangential, contact, rotary) are frequently registered in the interplanetary medium during experimental studies with the help of SC. The determination of types of discontinuities observed in a solar wind and orientation of their fronts, investigation of their stability are of interest [*Rice et. al., 2003; Lee, 2000; Barkhatov et al.., 2003*]. When studying jumps of parameters of interplanetary plasma, several tasks are devoted to definition of inclinations of discontinuities' fronts [*Haaland, S. et.al., 2004; Sonnerup, B.U.O., et.al., 2004*]. For this purpose the method of «minimum variance» is usually applied, which is based on studying of the behavior of specific plasma parameters (density, velocity, magnetic field components) obtained on board a one (single-spacecraft method) or several SC (multi-spacecraft method). These methods are grounded on the modified law of weight preservation and the empirical models of discontinuities obtained using statistic data. The weakness of such approach is that often it is impossible to separate tangential and rotary discontinuities, which leads to discrepancy in definition of orientation of fronts.

In contrast to the above mentioned techniques, our research develops neural network technology of division of jumps in the registered parameters of space plasma and the magnetic field into classes.

The results of our classification are preliminary and obligatory for the definition of orientations of discontinuities' fronts. For classification, the artificial neural network (ANN) of «Cohonen layer» type is designed, which allows to perform automatic classification of jumps of solar wind and interplanetary magnetic field parameters registered on board a SC WIND. The results of ANN-classification are compared with «manual» classification. In the paper the alternative way of determination of orientation of fronts is also proposed. This way is applicable after classification of jumps is done. As a result on the basis of one-dimensional observations, for discontinuities of established classes, it is possible to determine orientations of surfaces' planes. Evolution of the obtained shock waves is also studied.

2. Magnetohydrodynamic principles of classification

The discontinuities were classified on the basis of the scalar part of conditions for magnetohydrodynamic (MHD) discontinuities. The tangential discontinuity corresponds to the non-changing sums of gas-kinetic and magnetic pressure. The contact discontinuity complies with the permanence of speed and magnetic field. The rotary discontinuity is also observed at the permanence of speed and density of plasma and magnetic field. The shock waves are characterized by an increase of plasma density, constant value of normal component of magnetic field when magnetic field is increasing (fast), or reducing (slow) behind a discontinuity. Only scalar part of discontinuity conditions can be used for classification purposes by our method. This scalar part of conditions adapted for our classification task is shown below:

- Tangential: $\sum P = P + \dfrac{H^2}{8\pi} = const$ (1)
- Contact: $V = const$, $H = const$ (2)
- Rotary: $V = const$, $H = const$, $N = const$ (3)
- Fast shock and slow shock waves: $H_n = const,\ N>0,\ [H]>0$ *(fast) and* $H_n = const,\ N>0,\ [H]<0$ *(slow)* (4)

In the present study, the classification of discontinuities was carried out by one parameter: N, |B| or their combination accordingly (1-4). Two algorithms of classification were developed. The first algorithm starts with differentiation of discontinuities on the basis of the sum of pressures and the second – with differentiation on the basis of magnetic field (Table below).

<table>
<tr><th colspan="6">First algorithm start with differentiation of discontinuities on the basis of the sum of pressures</th></tr>
<tr><td rowspan="5">First step of classification on ΔP parameter</td><td rowspan="4">All other cases for ΔP parameter</td><td rowspan="4">Second step of classification on N parameter</td><td rowspan="2">Increase N</td><td rowspan="3">Third step of classification on |B| parameter</td><td>Increase |B| correspond to FAST SHOCK</td></tr>
<tr><td>Cases for which |B|=const correspond to CONTACT DISCONTINUITY</td></tr>
<tr><td>Decrease N</td><td>Decrease |B| correspond to SLOW SHOCK</td></tr>
<tr><td colspan="3">Cases for which N=const correspond to ROTARY DISCONTINUITY</td></tr>
<tr><td colspan="5">Cases for which ΔP=const correspond to TANGENTIAL DISCONTINUITY</td></tr>
</table>

<table>
<tr><th colspan="6">Second algorithm with differentiation on the basis of a magnetic field</th></tr>
<tr><td rowspan="5">First step of classification on |B| parameter</td><td rowspan="3">All other cases for |B| parameter</td><td rowspan="3">Second step of classification on ΔP parameter</td><td rowspan="2">All other cases for ΔP parameter</td><td rowspan="2">Third step of classification on |B| parameter</td><td>Increase |B| correspond to FAST SHOCK</td></tr>
<tr><td>Decrease |B| correspond to SLOW SHOCK</td></tr>
<tr><td colspan="3">Cases for which ΔP=const correspond to TANGENTIAL DISCONTINUITY</td></tr>
<tr><td rowspan="2">Cases for which |B|=const</td><td rowspan="2">Fourth step of classification on N parameter</td><td colspan="3">All other cases for N parameter correspond to CONTACT DISCONTINUITY</td></tr>
<tr><td colspan="3">Cases for which N=const correspond to ROTARY DISCONTINUITY</td></tr>
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3. Outcomes of numerical experiments

The self-learning ANN of Cohonen layer type was created for the purpose of classification [*Barkhatov et al.., 2006*]. In this network, correction and storage of image corresponding to a particular part of the whole group of considered events occurs. Thus, the network is capable of generating similar images attributing them to one class.

Using the above specified technique of classification by neural network, 82 discontinues in the solar wind, registered in 1996-1999 on SC WIND were analyzed for their subdivision into types. The overall performance of the neural network and correspondence of the executed classification to real situation is verified by comparison of results of classifications by the first and second algorithms. In case of success, the results of classification by the first and the second technique should be the same. The high coincidence (87%) of classification results by two independent algorithms testifies to the reliability of the created technique of classification.

Verification of reliability of neural network classification in addition is executed by «manual» classification applying the same algorithm as above. The peculiarity of «manual» classification is the possibility of human tester to work with all cases simultaneously. The neural network works with one particular event at a time, and all other events at that time are present as factors of neural network adjustment and their «clearness» depends on the quality of the network training. Comparison of results for different variants of classification showed concurrence in 75% of cases, which also testifies to reliability of the created classification technique.

Thus, among 82 considered cases it was possible to reliably define and classify 12 contact and 20 tangential discontinuities, 30 fast and 20 slow shock waves.

4. Establishing of orientation of discontinuity front planes

Outgoing from the system of conditions for particular types of abrupt changes (jumps) of interplanetary plasma parameters, it is possible to make conclusions about the orientation of their planes. The main source of the information in the solution of this problem is the information on the behavior of IMP components and the flow velocity components. The construction of discontinuity planes is meaningful only after the realization of classification. For rotary discontinuities and shock waves, magnetic field component normal to surface of these types of discontinuities during the jump is considered to be permanent – H_n=const. For tangential and contact discontinuities, components of magnetic field and speed, normal to surface of these types of discontinuities during the jump are considered to be absent – $H_n=V_n=0$ (for tangential discontinuity) and Vn=0 (for contact discontinuity) .

For example, the time functions of parameters measured on spacecraft for various events (Fig. 1, 3, 5) and their obtained planes of discontinuity surfaces (Fig. 2, 4, 6) are shown. Date and time of a jump are indicated on top of the plot. On axes the arbitrary units are plotted.

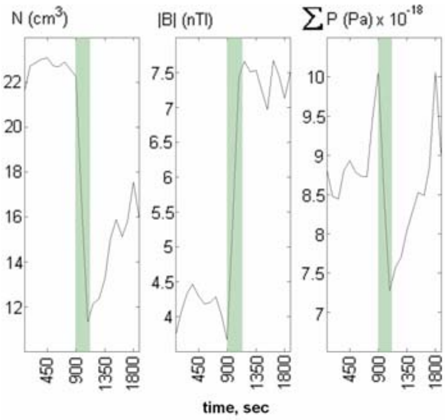

Fig. 1. The parameters of event 04/04/96 of shock wave type received by measurements on SC

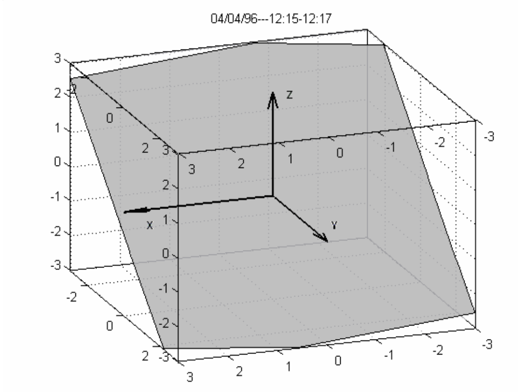

Fig. 2. Settlement plane of event 04/04/96 of shock wave type in solar-ecliptic coordinate system in arbitrary units

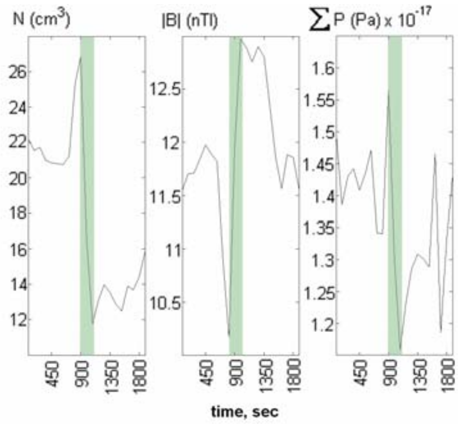

Fig. 3. The parameters of event 16/03/96 contact of discontinuity type received on the basis of measurements on SC

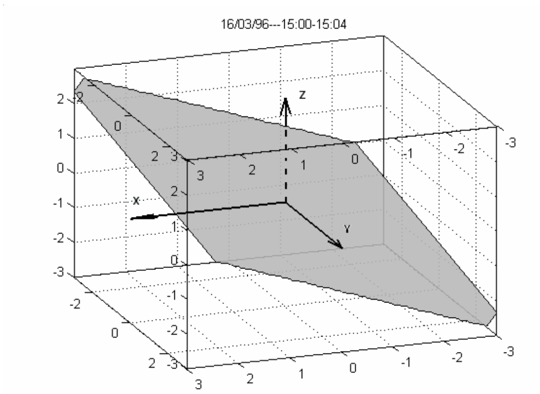

Fig. 4. Settlement plane of event 16/03/96 contact of discontinuity type in solar-ecliptic coordinate system in arbitrary units

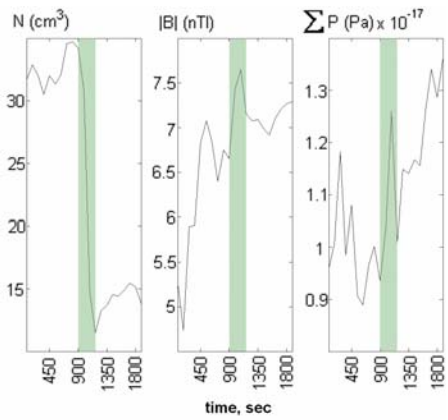

Fig. 5. The parameters of event 06/06/97 of tangential discontinuity type received on the basis of measurements on SC

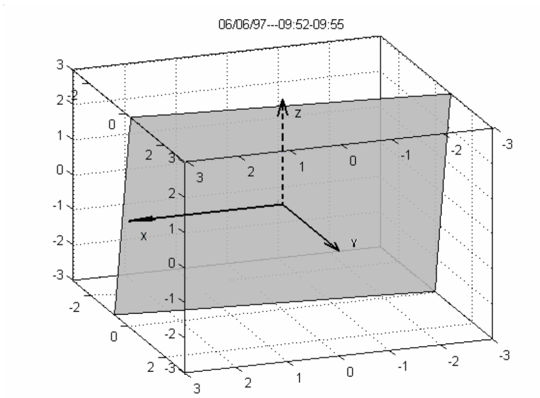

Fig. 6. Settlement plane of event 06/06/97 of tangential discontinuity type in solar-ecliptic coordinate system in arbitrary units

5. Analysis of evolution of established cases of shock waves

The analysis of evolution of cases complying with the shock waves was done. It is known [*Kulikovskiy and Lyubimov, 1962*], that two waves – fast $V_1 > V_{fms}$ and slow $V_{sms} < V_1 < V_A$ correspond to evolutionary shock waves (V_A and

$V_{fms/sms}$ – velocities of propagation of Alfven, fast and slow magnetosound waves). The possibility of speed calculation for fast and slow magnetosound waves for the shock waves defined as a result of classification allows to show their evolution areas (see a Fig. 7). For these cases in Fig. 7, the speed of the shock waves is shown with points. Apparently, points do not get into the evolution area since the speed of the shock waves is always higher, than V_{FMS} . However it does not let us assume that evolutionary shock waves are not present in the available data sample, since areas containing our shock waves comply only with the necessary evolution conditions.

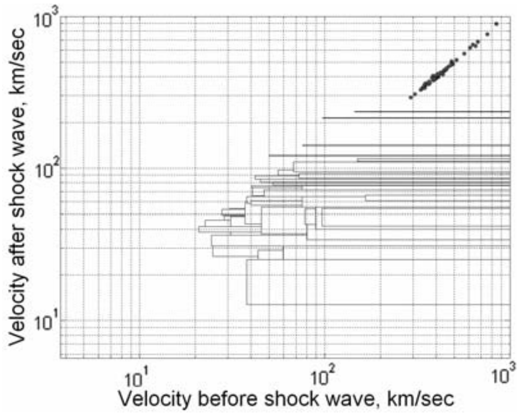

Fig. 7. Evolution areas and jumps of medium velocities of investigated shock waves. Axes are presented in a logarithmic standard

6. Conclusion

In the given paper on the basis of one-liquid MHD approach with application of artificial neural networks technology, the technique of automatic division of jumps of registered parameters of space plasma and magnetic field into classes adequate to the known types of discontinuities is developed. For this purpose the classification ANN of «Cohonen layer» type was developed and classification of jumps of parameters registered on board a SC WIND in 1996-1999 by two different algorithms was executed. Among 82 considered cases it was possible to reliably define and classify 12 contact and 20 tangential discontinuities, 30 fast and 20 slow shock waves. Reliability of the network performance was checked and confirmed by the comparison of results of both ANN classifications with classification executed «manually» by the same algorithms. For discontinuities of particular classes, the method to determine their surface plane orientation is developed and applied in a solar wind by one-dimensional observations on board SC. The evolution analysis of the found shock waves is performed and has shown their potential instability.

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