NUMERICAL SIMULATIONS OF A SUBCRITICAL QUASIPERPENDICULAR SHOCK: SPATIO-TEMPORAL AND NONLINEAR DATA ANALYSIS TECHNIQUES

Soucek J. [(1)], **Tsubouchi K.** [(2)], **Lembege B.** [(3)], **Dudok de Wit T.** [(4)]

[(1)] LPCE/CNRS, 3A, Av. de la Recherche Scient., Orleans, France, E-mail: soucek@ufa.cas.cz
[(2)] CETP/IPSL/CNRS, 10-12 Av. de l'Europe, Velizy, France, E-mail: ken.tsubouchi@cetp.ipsl.fr
[(3)] As (2) above, but E-mail: bertrand.lembege@cetp.ipsl.fr
[(4)] As (1) above, but E-mail: ddwit@cnrs-orleans.fr

ABSTRACT

Applications of several less common nonlinear data analysis tools to plasma simulation data are presented. Data issued from full particle simulations of quasi-perpendicular shock are analyzed with wavelet bicoherence and nonlinear parametric models in order to identify some properties of the nonlinear processes present at the shock. We take advantage of the unprecedented resolution of simulation data which makes these tools applicable, but we also consider their possible use for analysing the impact of decreased spatial resolution (for example to four observation points as in case of the CLUSTER satellite experiment).

ANALYSIS TECHNIQUES

Large increase in the performances of recent powerful supercomputers has allowed for highly realistic numerical simulations of many space plasma processes and such simulations have become a widely accepted form of a physical experiment. Comparing to satellite or/and laboratory experiments, these simulations have the advantage of almost arbitrary spatial and temporal resolution and unprecedented statistical content of the obtained datasets. Because of these unique features, the data can be processed using more sophisticated statistical tools which can bring deeper insight into the physics of the simulated processes, especially if the non-linear contribution to the waves dynamics is strong. However, these possibilities are often overlooked and the simulation data are analyzed with only few simple tools.

In this paper, we present application of such tools to electromagnetic fields components obtained from full particle simulations of a quasi-perpendicular shock propagating in subcritical regime, where nonlinear effects are not too strong; simulations conditions for exciting the shock are similar to those already used before [1]. In the present case, the dispersive effects are important (emission of an upstream whistler wave train) while dissipation brought by ion reflection is relatively poor.

In order to identify the whistler waves contributing to the wave train, we apply the wavelet correlation which gives us the corresponding dispersion properties. The non-linear processes associated with the generation of the whistler waves are approached with wavelet bicoherence analysis [2] and non-linear parametric (NARMAX) models [3]. These techniques allow to identify the degree of nonlinearity and to localize the spatial domain where the nonlinear processes take place. Furthermore, several de-noising techniques (like for example the singular value decomposition) are applied to reduce the influence of particle noise present in this type of simulations.

Second, using the simulation data, we attempt to mimic the four point local data observations of the CLUSTER satellite array in order to validate possible application of the statistical techniques to real satellite observations. We compare the results obtained from the full dataset and the four-points data in a realistic scenario of a bow shock crossing to quantify the uncertainty brought to the measurements by reducing the spatial resolution to four points. Advantages and limitations of the various data processing tools in both applications are discussed.

REFERENCES

[1] B. Lembege and J.M. Dawson, ``Self-consistent study of a perpendicular collisionless and nonresistive shock", *Phys. Fluids*, vol. 30(6), pp. 1767-1788, 1987

[2] T.Dudok de Wit and V.Krasnoselskikh, ``Wavelet bicoherence analysis of strong plasma turbulence at the Earth's quasi-parallel bow shock", *Phys. Plasmas*, vol. 2, pp. 4307-4311, November 1995

[3] S.Chen and A.Billings, ``Representations of non-linear systems: the NARMAX model", *Int. J. Control*, vol. 49(3), pp. 1013-1032, 1989