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Bayesian Coronal Seismology

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Abstract

In contrast to the situation in a laboratory, the study of the solar atmosphere has to be pursued without direct access to the physical conditions of interest. Information is therefore incomplete and uncertain and inference methods need to be employed to diagnose the physical conditions and processes. One of such methods, solar atmospheric seismology, makes use of observed and theoretically predicted properties of waves to infer plasma and magnetic field properties. A recent development in solar atmospheric seismology consists in the use of inversion and model comparison methods based on Bayesian analysis. In this paper, the philosophy and methodology of Bayesian analysis are first explained. Then, we provide an account of what has been achieved so far from the application of these techniques to solar atmospheric seismology and a prospect of possible future extensions.

Keywords: magnetohydrodynamics (MHD); methods: statistical; Sun: corona; Sun: oscillations

1. Introduction

Solar atmospheric seismology aims to obtain information about difficult to measure physical parameters in the solar atmosphere by a combination of observed and theoretical properties of magnetohydrodynamic (MHD) waves (Uchida, 1970; Rosenberg, 1970; Roberts et al., 1984; Nakariakov & Verwichte, 2005; De Moortel, 2005; Banerjee et al., 2007; De Moortel & Nakariakov, 2012; Arregui, 2012). The technique has been successful in the determination of a number of parameters in coronal, prominence, and chromospheric plasmas such as the magnetic field strength (Nakariakov & Ofman, 2001), the radial density contrast and the Alfvén travel time (Goossens et al., 2008), the coronal density scale height (Andries et al., 2005a), or the Alfvén speed (Verwichte et al., 2013).

Seismology diagnostic studies are based on the adoption of a theoretical model to explain the observed oscillations, the solution of the forward problem to obtain the theoretically predicted wave properties as a function of the model parameters, the comparison with the observed wave properties, and the solution to the inverse problem to extract the magnetic and plasma parameters of interest. The forward problem does not involve difficulties other than those arising from the analytical/numerical solution of the MHD wave equations. The inverse process of extracting information on the physical conditions from measured wave properties is a more involved task. The solution to such inverse problem might not exist or be unique. Measurements of wave properties have always a certain degree of uncertainty associated to e.g., the existence of noise. Even if there is a unique analytical relation between one observable and one model parameter, the presence of noise can make the inversion completely useless. In other cases, inferring parameters from observables may consist in the solution of a mathematically ill-posed problem in which the amount of unknowns outnumbers that of observables. In summary, the solution to the inverse problem has to be pursued under conditions in which direct access to the physical conditions of interest is not possible and indirect observational information is always incomplete and uncertain. For these reasons, extracting information on physical parameters by comparison of theoretical model predictions with observed data has to be carried out in a probabilistic framework. This means that our conclusions will at best be probabilities, where probability refers to the quality that enables us to quantify uncertainty in terms of degree of belief.

Once the inversion problem is correctly solved, one must realise that the resulting inference depends on the underlying theoretical model that has been assumed. This makes model comparison the next necessary task to be performed in order to assess the plausibility of any obtained inference. This requires to devise methods to perform a comparison between alternative hypotheses that enable us to present different theoretical models to the same data to assess, in a quantitative manner, which model is favoured by the data.

A recent development in solar atmospheric seismology has been the adoption of the Bayesian approach to the inference and model comparison problems. This comes from the realisation that the Bayesian approach is the only cor-

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