マルコフ確率場モデルに基づく伝搬ベクトル推定法の提案

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A Proposal of the Direction Finding Method based on Markov Random Field Model

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With the utilization of outer space using communication and meteorological satellites and so on, the importance of the investigation of space environment around the earth is emphasized. Investigating characteristics of plasma waves observed by scientific satellites in the earth's plasmasphere/magnetosphere is an effective key to know not only the generating mechanism of the waves but also the plasma environment which influences generation and propagation conditions of the waves. Therefore, in this study, we developed a method for direction finding of plasma waves from waveform or spectrum data measured by plasma wave receiver. Although a method proposed by Means [1] is known as the simplest method for a direction finding of plasma waves, it works under the assumption that measured data consists of only one plane wave and the wave normal vector must be perpendicular to the polarization plane of the magnetic wave field. Thus this method is unable to apply when multiple waves are simultaneously detected at an observation point. Actually, in the previous studies using observation data from the Akebono satellite, good results were obtained by the Means' method when a plane wave assumption is clearly satisfied, that is, in case of direction finding of Omega signals, lightning whistlers and so on. But it is difficult to apply a plane wave assumption to natural plasma waves which are continuously observed in temporal and broadband characteristics such as hiss and EMIC waves. In order to solve this problem, a wave distribution function (WDF) method was proposed [2,3]. According to the WDF, wave normal vectors are represented by energy density distribution of wave elements under the restriction that the arrival waves satisfy dispersion relation of plasma wave. However, since it generally becomes an ill-posed problem, it is necessary to assume some kind of prior information. In order to solve this ill-posed problem effectively, several types of solution method were proposed; (1) a method based on maximum entropy assumption [4], (2) a method which assumes neighboring energy density distribution correlates each other and so on. Although the former method can perform very good estimation including a case that wave sources are widely spread, this method is more sensitive to noise than the latter method. The latter method is not sensitive to noise due to a regularization term, but the reconstructed image estimated by this method becomes dull. In this study, we propose a method based on Bayes estimation. This method is characterized by little computational complexity and insensibility to noise compared with the conventional methods. We introduce the Markov random field into the proposed method as prior information of energy density distribution. By introducing this assumption, it is possible to calculate approximate posterior distribution using variational Bayes with small computation time. Furthermore, it is also possible to determine the regularization parameter which maximizes the marginal likelihood.

近年の通信衛星や気象衛星などによる宇宙空間の利用にともない, 地球周辺宇宙環境の調査の重要性が高まっている. 科学衛星を用いたプラズマ波動観測においては, 波動の伝搬特性を調べることで, 波動の発生メカニズムだけでなく, 波の励起・伝搬に関わる宇宙プラズマの状況を知る有効な手がかりとなる. そこで本研究では, プラズマ波動の波形あるいはスペクトル観測データから, 波動の伝搬ベクトルを推定する方法の開発と評価を行った. プラズマ波動の伝搬ベクトル推定法として, Means 法 [1] が最も簡便な方法として知られているが, 同手法は到来波が 1 波と仮定し, 磁界成分の偏波面に垂直な方向を伝搬ベクトル方向とする推定法のため, 同時に複数の波源から観測点に波が到来する場合には適用できない. 実際, あけぼの衛星による観測においても, オメガ信号や雷起源ホイスラなど, 明らかに 1 波と仮定して差し支えないプラズマ波動については, Means 法で良好な結果が得られるが, ヒスや EMIC 波動などのように, 時間・周波数的に連続的に観測される自然プラズマ波は, 1 波の仮定が必ずしも成り立つとは限らない. このような問題に対し, プラズマの分散関係を満たす電磁波動の伝搬ベクトル推定法として波動分布関数法がある [2,3]. 波動分布関数法は, 複数の伝搬ベクトルを表現するために, 到来角に対するエネルギー密度分布を用いる. しかし, 一般には複数の到来波を仮定すると劣決定問題となるため, なんらかの先験情報を仮定する必要がある. これまでに, その仮定としてエントロピー最大化に基づく方法 [4], エネルギー密度分布が近傍角度で相関をもつとする方法 [5] が提案されている. 前者の方法は, 波源の広がりを含め, 非常に良好な推定が行えるが, ノイズによる影響を受けやすい. また後者は正則化項によってノイズの影響を受けにくいが, 広がりを持った分布として推定されるという特徴がある. 本研究では, 従来手法に比べ, 計算量が少なくノイズに強いベイズ推定に基づく手法を提案する. 提案手法では, エネルギー密度分布の先験情報としてマルコフ確率場を仮定する. この仮定により, 変分ベイズ法を用いて高速に近似事後分布を求めることが可能となるだけでなく, 周辺尤度を最大化するような正則化パラメータを決定することが可能となった.

参考文献

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