METHODS AND SOFTWARE FOR COSMIC RAY SCINTILLATION STUDIES

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Methods and programs for statistical processing of cosmic ray intensity measured in the world-wide network are proposed.

The main instrument in scintillation studies is the cosmic ray spectrum constructed from the intensity onservation /I/. The problem of psctrum estimation from measured time series has a long-standing history, but the specificities of the phenomenon of interest do not permit the direct use of the classical methods. One of such specificities is that besides the appearance of regular trends, which can in principle be eliminated by different filtration methods, in the periods most interesting from the viewpoint of the physics of processes (for instance, Forbush decreases, solar flares) the statistical characteristics of the process undergo essential reconstruction, i.e. the process besomes nonstationary. In this case the concept of spectrum is not defined, and the methods based on Fourier transform, Blackman-Tusky method) give wrong results. The technique usual in this situation, i.e. discrimination of quasistationary regions, encounters the following difficulties. Such regions, if any, can be very short. When based on a small amount of data, the methods using Fourier transform are known to give inaccurate results, in particular, they do not allow us to separate close frequencies, whereas the second specific feature is just the necessity to separate close frequencies, some of which can be associated with a certain process in solar space. For a better separation of near frequencies in short regions, the so-called autoregressive methods have lately been used for spectrum estimation /2/. These methods suggest introduction of an additional possibility to describe the process by an autoregressive model

$$x_{t+1} = \sum_{i=0}^{p} a_i x_{t-i} + \xi_t , \quad t = 0, 1, \dots \tag{I}$$

where ξ_t is the sequence of independent random quantities of a certain unkhown order p. This assumption is based on the fact that a wide class of stationary processes can be described by such a model. The coefficients of regression are in this or that way estimated under this assumption for a certai chosen order p, and then the single-valued analytical estimate of the spectrum is found from these coefficients. Such an approach, using different algorithms for estimating the coefficients (of the type of Berg, Levinson-Durbin, Pisarenko, and other methods), is also realized in our methods. In some cases it gives satisfactory results. But it cannot be applied to essentially nonstationary processes either.

To eliminate these difficulties we have proposed the following two approaches. One of them suggests the description of a process by an autoregressive model in which the coefficients vary in time

$$x_{t+1}=\sum_{i=0}^{p} a_i(t)x_{t-i}+\xi_t, \quad t=0,1,\dots \tag{2}$$

Each coefficient is represented as a series in a given complete set fo functions $\{\varphi_k(t)\}$

$$a_i(t)=\sum_{k=1}^{N} c_{ik}\varphi_k(t) \tag{3}$$

with the unknown coefficients $\{c_{ik}\}$. As a set of functions one can choose, in particuler, a power series $\{1, t, t^2, \dots\}$. Then, using the method of least squares, one can calculate the coefficients for the chosen order p of the model and for the number N in the expansion (3). The order p of the model and the number of terms N in the expansion ca be chosen, so to say, in the best possible way.

Such an approach makes it possible to introduce the concept of an instantaneous spectrum for a nonstationary process. At each time moment (estimated from the time series of lenght T) the parameters correspond to an autoregressive model with known constant coefficient $a_i^T=\sum_{k=1}^{N} c_{ik}\varphi_k(t)$

$$x_{t+1}=\sum_{i=0}^{p} a_i^T(t^*)x_{t-i}$$

Such a process will be thought of as stopped at a time moment t (starting at some initial point x_0, it passes through a stationary sequence). This process corresponds to a psectrum which can be calculated analytically from the moment t will be called a t -instantaneous **spectrum** of the nonstationary process (2).

Arranging the sequence of instantaneous spectra with respect to t , one obtains a dynamical picture of reconstruction of a nonstationary process.

The other approach to investigation of a nonstationary process is based on the on-line method for estimating the parameters of the model (2), i.e. on the stochastic approximation method. Let the coefficients $\{a_i^T(t^*)\}$ be time-independent (model (I)), then the algorithm of stochastic approximation for estimating $\{a_i\}$ for a chosen order p of the model has the form ($\hat{a}$ is the vector of parameter estimation, $\varphi_t = (x_1, \dots, x)$ is the measured time series):

$$\hat{a}_{t+1} = a_t - \gamma_t \varphi_t \left(x_{t+1} - \sum_{i=0}^{p} \hat{a}_i x_{t-i} \right) \qquad (4)$$

Under certain conditions, if the sequence γ_t tends to zero with an appropriate velocity, one can show (see, for instance, /3/) that as $t \to \infty$, the estimates of $\hat{a}_t$ converge to the vector of the coefficients a of model (I). It is a disadvantage of the method that it needs a large sample, which is hardly to be provided under the described conditions. At the same time, this difficulty can be eliminated if we reject the requirement concerning constancy of the coefficients and pass over to the model (2) without expanding a in the series (3).

In this case, to estimate the coefficients of the model (2), we use the algorithm /4/, in which the sequence γ_t is chosen differently. One can show that under certain conditions on the growth of the coefficients $a_i(t)$ and for a corresponding rate of convergency γ_t to a certain constant, the algorithm (4) will trace the trend of the parameter $a_i(t)$. Under these assumptions one can provide a large sample of data since the series need not necesserily be stationary, and the algorithm works well. The way of constructing an instantaneous spectrum is the same as described above.

The software considered includes all the approaches described above, namely, direct Fourier transform and its modifications, autoregressive and instantaneous spectrum methods. Being used in various combinations, they prove helpful in handling the time series. The methods have been verified in special tests. Some results of investigation of scintillations using these methods are presented in /4/.

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