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Forest Wildfire Modelling and Prediction in Russia

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The wildfire (forest fire) is a natural disaster that causes great economical losses in many regions of Russia. In the present work the joint sample of daily values of the number of forest fire seats and the Nesterov meteorological index in Irkutsk region, seasons 1969–1988, are investigated. It appears that the evolution of forest fire is well described by a vector autoregression process based model. The prediction of the future numbers of fire seats can be performed using special computer algorithm, which is shown to produce accurate and reliable estimates up to 2 days ahead.

Key words and phrases: forest fires, heteroscedasticity, vector multiplicative seasonal autoregressive coefficient Spearman, forecast.

1. Introduction

The phenomenon of forest fire is one of the most devastating natural disasters in many regions of Russia. The process of forest fire evolution is very fast, is not deterministic, and cannot be controlled by man.

However, there is a number of well-established methodologies of prevention and neutralisation of the consequences of forest fire. For these methodologies to be efficient, it is crucial that the process of forest fire can be modelled and predicted some days ahead. A reliable and accurate forecast allows to wisely allocate limited resources and concentrate on the optimal measures.

Common requirements to forest fire monitoring and forecasting are regulated by Russian state standard GOST R 22.1.09–99 "Safety in emergencies. Monitoring and forecasting of forest fires. General requirements" [1]. According to this document, the severity of forest fire danger is defined by the complex meteorological index of V. G. Nesterov:

$$\mathrm{NI} = \sum_{i=1}^{n} T(T - T_d),$$

where T is the air temperature (in Celsius degree), T_d is the dew point (in Celsius degree), n is the number of days since last precipitation (precipitation values < 2.5 mm are ignored) [2].

2. MAR(1)S Model

To assess statistical properties of the forest fire evolution process and its relation to the meteorological factors, the joint sample of daily values of the number of forest fire seats and the Nesterov index in Irkutsk region, seasons 1969–1988, has been investigated:

$$X_{t_k} = \begin{pmatrix} \mathrm{FS}_{t_k} \\ \mathrm{NI}_{t_k} \end{pmatrix}, \quad k = p \cdot k_p,$$

where $p = 20$ is the number of seasons (periods), $k_p = 214$ is the number of observations per season (from April 1 to October 31, fig. 1).

It turns out that the data can be well described by a mathematical model *MAR(1)S* (*M*ultiplicative *AR(1)* with *S*easonal), consisting of the following 3 components:

– multiplicative seasonal component $s(\tau)$;
– vector autoregression VAR(1) [3] trend y_{t_k};

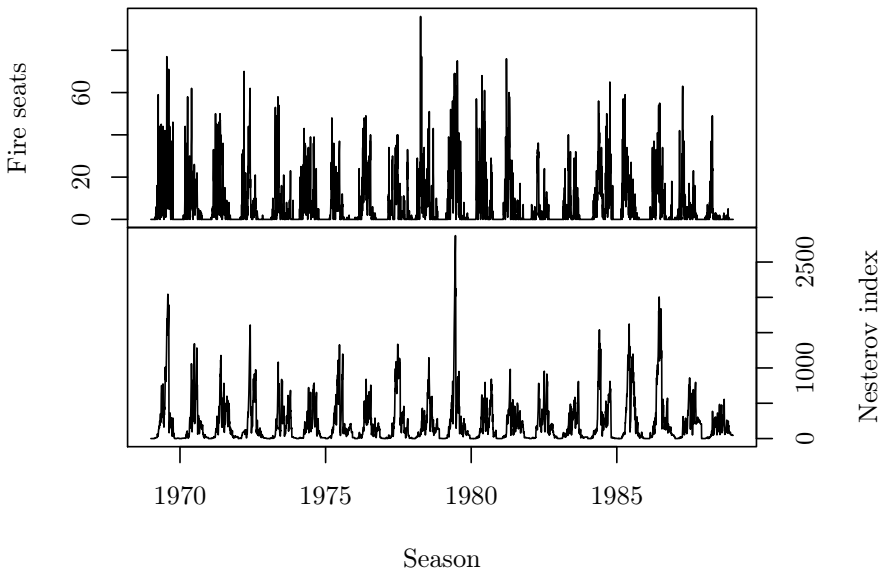

Figure 1. Raw data

– bivariate skew-normal [4] random component e_{t_k}.

$$\begin{aligned} x_{t_k} &= \exp(y_{t_k} + s(\tau_{t_k})), \\ y_{t_k} &= A \cdot y_{t-1} + e_{t_k}, \\ e_{t_k} &\sim SN_2(\sigma\Omega\sigma^{\mathsf{T}}, \alpha). \end{aligned} \tag{1}$$

The MAR(1)S model allows to perform short-term forecast of the number of fire seats. Reliable estimates of the Nesterov index values are usually available up to 3 days ahead [5]. In the present work the future numbers of forest fire seats were simulated using given values of the Nesterov index. The corresponding functional computer algorithm has been implemented in R and is freely available under the GPL (version 3 or later) conditions.

VaR (Value-at-Risk) methodology is widely used in financial mathematics to characterise potential losses caused by extreme events [6, 7]. The forest fire is a typical example of such an extreme event. Proposed forecast approach allows not only to calculate expected severity of forest fire danger n days ahead, but also to estimate the Value-at-Risk for any given confidence level.

The forecast method was tested on the seasons 1989–1990 data (Fig. 2). It appears that MAR(1)S prediction performs much better than plain Nesterov index (see Table 1). Investigation of the statistical properties of the $\mathrm{VaR}_{90\%}$ values showed that the prediction is reliable and accurate for $n \leqslant 2$.

Table 1

Sample estimates of Spearman rho correlation values between predicted and actual numbers of forest fire seats

Forecast method	1989	1990
Plain Nesterov index	0.21	0.39
MAR(1)S, 1 days ahead	0.76	0.81
MAR(1)S, 2 days ahead	0.56	0.66
MAR(1)S, 3 days ahead	0.41	0.56

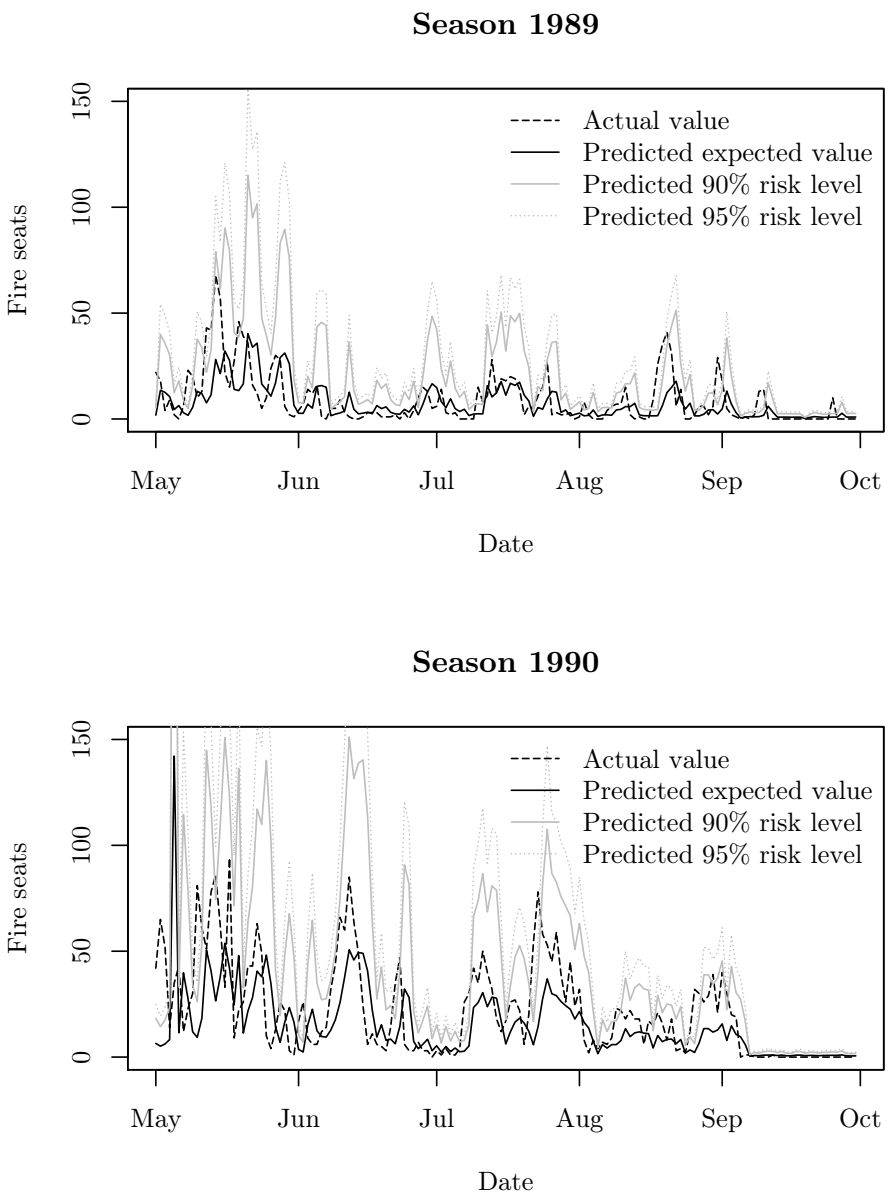

Figure 2. Prediction of the severity of forest fire danger, 2 days ahead

3. Results

The joint sample of daily values of the number of forest fire seats and the Nesterov meteorological index in Irkutsk region, seasons 1969–1988, have been investigated. The stochastic process of forest fire evolution can be well described by a 3-component model MAR(1)S, which takes into account the dynamic nature of the process.

The model can be readily used for the short-term forecast of the expected and potential severity of the forest fire up to 2 days ahead. It is shown that proposed method performs much better than plain meteorological index specified by Russian standard.

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Моделирование рисков возникновения и прогнозирование пожароопасных ситуаций в России

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Проведен статистический анализ данных по лесным пожарам в Иркутской области и построен ряд математических моделей, описывающих соответствующие временные ряды. На их основе проведены численное моделирование и оценивание количества пожаров в каждый сезон, а также проанализированы их статистические связи с индексом Нестерова. Анализ результатов проведенных исследований, разработанные модели, в отличие от индекса Нестерова, позволяют получить значительно более точный прогноз на периоды до трех суток.

Ключевые слова: лесные пожары, гетероскедастичность, векторная мультипликативная сезонная авторегрессия, коэффициент Спирмена, прогноз.