Application of a dynamic-stochastic prediction method to forecasting the state parameters of the atmospheric boundary layer based on data of radiometric and sodar measurements

V.S. Komarov, S.N. Il'in, A.V. Kreminskii, E.N. Kadygrov,* A.V. Lavrinenko, N.Ya. Lomakina, S.L. Odintsov, Yu.B. Popov, A.I. Popova, and V.A. Fedorov

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
** Central Aerological Observatory, Dolgoprudny*

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The results obtained by application of the dynamic-stochastic method, based on the use of Kalman filtering algorithm and two-dimensional regression model, to the problem of ultra short-term forecast of temperature and wind in the atmospheric boundary layer from the data of radiometric and sodar measurements are discussed.

Introduction

It is known that the problem of super short-term (3 hours ahead) forecast of the parameters of the state of the atmospheric boundary layer (ABL) and, in particular, of temperature and wind has not been solved yet. One of the reasons is the absence of means to acquire data on the vertical distribution of the aforementioned parameters with high spatial and temporal resolution. Indeed, the data of standard temperature and wind sounding used in practice of meteorological investigations of the ABL are characterized by low height resolution, insufficient reliability at the heights lower than 0.5 km (because of a high speed of radiosonde ascend) and small repetition frequency of sounding (twice a day: at 0 and 12 of Greenwich time). Real possibility of solving the problem of super short-term (from 1 to several hours ahead) forecast of temperature and wind in the boundary layer of the atmosphere has appeared only recently.

It is caused by the fact that new methods for remote sounding begin to be introduced into practice of monitoring of the atmosphere. The methods are based on the use of modern lidar, radiometric, and acoustic systems capable of estimating vertical distributions of temperature and wind in the boundary layer of the atmosphere with high spatial and temporal resolution. Besides, the important circumstance favoring solution of the problem of super short-term forecast with short time ahead is the fact that new non-traditional methods for such forecast have been developed in recent years. The methods are based on the use of dynamic-stochastic models and are realized with minimum of the initial data available.

One of such methods is the Modified method of clustering of arguments (MMCA) based on the use of the mixed difference dynamic-stochastic model and the algorithms of directed group running over (for optimization of the structure of this model) and minimax estimating for obtaining the estimates of its parameters. The MMCA was proposed by researchers from the Institute of Atmospheric Optics SB RAS and is described in Refs. 1 and 2. Applying it together with the method for optimal extrapolation of a random process (the latter is used for forecasting the meteorological parameters only at the ground level), one can solve the problem of super short-term forecast in the boundary layer of the atmosphere using the data of limited number of lidar, radiometric or sodar measurements.

The experience of using such a complex approach has been described in Refs. 2 and 3, where the results are presented of super short-term (4 hours ahead) forecast of zonal and meridional components of the wind velocity in the boundary layer of the atmosphere carried out on the basis of MMCA and the method for optimal extrapolation of a random process using data of wind measurements performed by means of a three-path correlation lidar.

Regardless of serious advantages of the MMCA over the regression methods (the main of which is the possibility of realizing it with only limited bulk of data available), its main disadvantage (if used in super short-term forecast) is the necessity of obligatory use of the method for optimal extrapolation of a random process or any another method providing such a forecast at the ground level or a level lying below the level of measurements).

So A.V. Lavrinenko, V.S. Komarov and Yu.B. Popov[4] have proposed a new technique of super short-term forecast of the parameters of the state of the atmosphere based on the algorithm of Kalman filtering and two-dimension dynamic-stochastic model of regression type that does not need using any other methods.

In this paper we present the results obtained by applying this technique to solution of the problem of super short-term (30 minutes to 3 hours ahead) forecast of temperature and wind from the data of radiometric and sodar measurements.

Before considering these results, one should remind some peculiarities of the algorithm used for such a forecast.

As in Ref. 4, we used the forecast model of the type

$$\xi_h(k) = \sum_{m=h-i}^{h+i} \sum_{j=1}^{K} d_{j,m}\xi_m(k-j), \qquad (1)$$

where $d_{j,m}$ are unknown coefficients to be estimated, which determine correlation between the estimated values of the field $\xi_h(k)$ and its values at the preceding time moments at a given height and neighbor height levels, i.e., $\xi_m(k-j)$ (here j is the current value of discrete time varying from 1 to k and determining the depth of the autoregression window, and m is the number of the height level, at which the forecast is being performed, m varies from $h-i$ to $h+i$ at $i = 1, 2, \ldots, n$ indicating the maximum number of information levels taken into account). However, actual values of the field $\xi_h(k)$ are not taken in the model (1), as in Ref. 4, but its centered values $\xi'_h(k) = \xi_h(k) - \overline{\xi}_k$ are used, where $\overline{\xi}_k$ is the mean value obtained by averaging over the data at five preceding moments in time.

The following formulas are used for estimating the unknown parameters $d_{j,m}$ in the model (1):

The equation of state of the form

$$\mathbf{X}(k+1) = \mathbf{F}(k)\cdot\mathbf{X}(k) + \mathbf{\Omega}(k), \qquad (2)$$

where

$$\mathbf{X}(k+1) = |d_{1,0}(k+1),\ d_{2,0}(k+1),\ d_{3,0}(k+1),\ d_{2i+1,0}(k+1),\ d_{1,1}(k+1),\ \ldots,\ d_{2i+1,k}(k+1)|^{\mathrm{T}}$$

is the vector of the state of the dimension $(2i+1)k$ (here T denotes the transposition), $\mathbf{F}(k)$ is the transition matrix for the discrete system of the dimension $(2i+1)k \cdot (2i+1)k$; $\mathbf{\Omega}(k)$ is the vector of random disturbances of the system (vector of the noises of the system); the model of measurements:

$$\mathbf{Y}(k) = \mathbf{H}(k)\cdot\mathbf{X}(k) + \mathbf{E}(k), \qquad (3)$$

where $\mathbf{Y}(k)$ is the vector of the centered values of the field ξ with the components $Y_i(k) = \xi_i(k) - \overline{\xi}_k$; $\mathbf{H}(k)$ is the matrix of observations of the dimension $(2i+1)k\cdot 1$; $\mathbf{E}(k)$ is the vector of the errors (noises) in measurements.

Based on Eqs. (2) and (3), the problem of estimation is solved by means of the linear Kalman filter.[5]

The technique[4] based on the use of two-dimension dynamic-stochastic model and the apparatus of Kalman filtering was studied in relation to its efficiency when applied to the problem of super short-term forecast of temperature and wind in the boundary layer of the atmosphere. The data of several series of radiometric (for temperature) and sodar (for wind) measurements were used for estimating the quality of such a technique. Measurements were carried out in January, July, and October, 2004 in the region of Tomsk (56.5°N, 85°E). In addition, the data on wind were added by corresponding measurements carried out in October 2004 at the meteorological mast situated on the territory of the Base Experimental Complex of the Institute of Atmospheric Optics SB RAS.

One should also note that the data on temperature measured by means of the remote temperature meter MTR-5 (Ref. 8) are obtained at 13 height levels: 0, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550 and 600 m. At the same time, the data on wind direction and speed were obtained at the heights of 10, 20, 30 and 36 m (using the meteorological mast) and 100, 150, 200, and 250 m (using a Volna-3 sodar).

To estimate the success of super short-term forecast carried out on the basis of the proposed algorithm with $\tau = 0.5$, 1, 1.5, 2, 2.5, and 3 hours ahead, the standard (rms) errors δ_ξ of such a forecast were used.

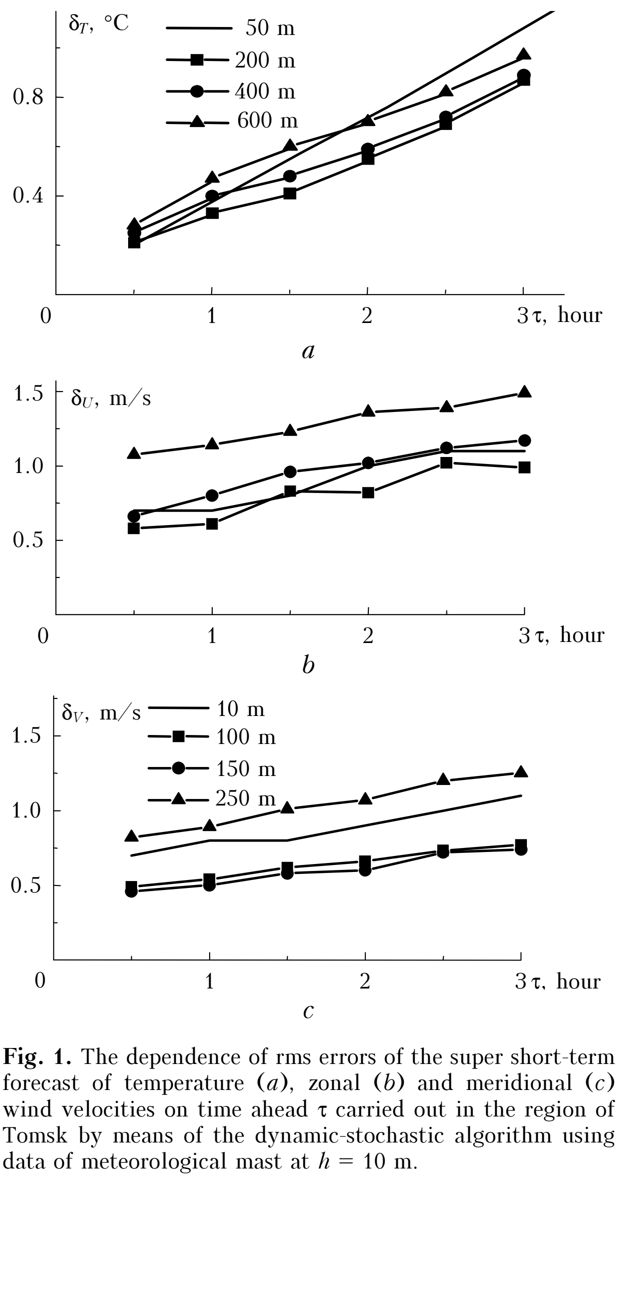

Fig. 1. The dependence of rms errors of the super short-term forecast of temperature (*a*), zonal (*b*) and meridional (*c*) wind velocities on time ahead τ carried out in the region of Tomsk by means of the dynamic-stochastic algorithm using data of meteorological mast at h = 10 m.

The results on accuracy of estimating the quality of the proposed algorithm of temperature, zonal and meridional components of wind velocity at the heights of 50, 200, 400, 600 and 10, 100, 150, 250, respectively, are shown in Fig. 1 as an example.

It follows from analysis of the figure and other obtained data that:

The proposed algorithm of super short-term forecast of temperature and orthogonal components of wind velocity in the boundary layer of the atmosphere based on Kalman filtering and two-dimension dynamic-stochastic model provides the best results of temperature forecast. Indeed, even at $\tau = 3$ hours the standard errors of super short-term forecast of temperature at all considered heights do not exceed 1.1°C, and at $\tau = 2$ hours these errors vary within the limits 0.5–0.8°C that is noticeably lower than the maximum admissible error of 1°C set for the troposphere by World Meteorological Organization.[6]

This algorithm provides the results of close accuracy at super short-term forecast of zonal and meridional wind velocities at the height of 10 m, when the data of the meteorological mast have been used, because the standard errors of such forecast at $\tau = 3$ hours vary within the limits 0.7–1.2 m/s.

The quality of super short-term forecast carried out by means of the proposed algorithm becomes a little bit worse in the case if this forecast has been performed for zonal and meridional wind velocities obtained from the data of sodar measurements. However, even in this case the standard errors $\delta\xi$ at $\tau = 3$ hours are within the limits 0.8–1.5 m/s, independent of the wind velocity component and the height level, i.e., this is comparable with the errors in radiosonde measurements of wind equal to 0.7–2.0 m/s (Ref. 7).

Thus, one can conclude, in general, that the developed algorithm based on the two-dimension dynamic-stochastic model and the procedure of Kalman filtering and applied for solution of the problem of super short-term (30 minutes to 3 hours ahead) forecast of temperature and wind in the boundary layer of the atmosphere from the data of radiometric and sodar measurements can be used in practice. However, the obtained results on estimation of its accuracy require additional examination and revision on the basis of longer time series of experimental observations, because of limited bulk of the initial data available.

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