Automated meteorological system for fast processing of aerological information, diagnostics, and forecasting the atmospheric state on mesoscales.

Part 1. Description of the system structure

V.S. Komarov, A.Ya. Bogushevich, S.N. Il'in, A.V. Kreminskii, Yu.B. Popov, and A.I. Popova

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

Received December 10, 2004

We describe the main functions, structure, and technical characteristics of an automated meteorological system developed at the Institute of Atmospheric Optics SB RAS. The system is intended for information provision (with the forecast data) in solving various applied problems.

Introduction

The solution of a wide range of applied problems associated with the monitoring of air pollution within limited air basins (for example, in a big city or an industrial zone), as well as with accident prevention during take-off and landing of aircraft, and with the increase of efficiency of lidar sensing of the atmosphere in bad weather (fog, heavy precipitation, etc.) requires not only the development of new and reliable methods for numerical diagnostics and forecast of meteorological fields on the mesoscale, but also the automation of obtaining, processing, and representation of aerological information. However, these problems are not yet solved properly.

In the recent years the Institute of Atmospheric Optics SB RAS has conducted wide investigations on the development of new methods for diagnostics and forecast of meteorological fields on the mesoscale and automated meteorological systems for information support in solving applied problems. Some results of these investigations are reviewed in Refs. 1–4.

It should be emphasized here that by now specialists from IAO have developed a lot of new methods for the spatial and temporal forecast of meteorological fields on the mesoscale. For the first time, these methods are based on the use of few-parameter models of the dynamic-stochastic type and Kalman filtering (see Ref. 4). Nevertheless, the problem of development of an up-to-date automated system realizing these methods and algorithms is still open.

The first version of such a system realizing some algorithms of data processing and diagnostics of mesometeorological fields, considered in Refs. 2 and 3, had certain limitations and disadvantages. In particular, this system did allow the input and processing of meteorological information in the form of standard KN-04 bulletins from a network of aerological stations. As a basic algorithm for the diagnostics of meteorological fields on the mesoscale, this system employed an insufficiently efficient algorithm based on the Modified Method of Clustering of Arguments (MMCA), whose realization required the data samples of a certain length $N = k + 1$ ($k \geq 5$ is the number of levels) and needed for combining with the method of optimal interpolation (extrapolation). In addition, this system did not include a module providing for the very-short-range forecast of parameters of the atmospheric state.

In this connection, it became urgent to develop such an automated meteorological system (AMS), which would be capable not only to provide for realization of algorithms of input and processing of spatially distributed aerological information and forecasting mesometeorological fields in space and time, but also to use the up-to-date information technologies and efficient software tools.

This paper, summarizing the results of our investigations in 2001–2003 on the development of an automated meteorological system, considers the main structure features, composition, and performance characteristics of this system.

1. Purpose and main functions of the automated meteorological system

The automated meteorological system, developed as a multifunctional and professionally oriented processing center, is intended for solving such problems as:

- spatial extrapolation of the layer-averaged values of temperature, zonal and meridional components of the wind velocity (these parameters are usually used for the forecast of atmospheric pollution and for the meteorological provision of military geophysics[4]) along a given trajectory or to a territory not covered by observations (to the depth of 250–300 km) from the results of routine measurements of a local network of aerological stations;

- objective analysis of mesometeorological fields (namely, fields of geopotential, temperature, dew points, and wind) in the given regions, using data of a local network of aerological stations with regard for the possible change in the size (within the mesoscale), orientation (about the north–south line), and spatial resolution (step) of a regular grid;
- very-short-term forecast (with the advance time of 6 to 12 h) of the atmospheric parameters (temperature and wind), carried out on the basis of measurements at some stations for the given region.

Consider the main functions of the AMS having in mind the problems listed above. For this purpose, let us use the AMS flow chart shown in Fig. 1.

As can be seen from Fig. 1, AMS is realized in the form of modules (subsystems), each performing its specific functions. These modules include:

1) subsystem for processing and transformation of the input information;

2) subsystem for spatial extrapolation of meteorological fields;

3) subsystem for objective analysis of mesometeorological fields;

4) subsystem for very-short-term forecast of the atmospheric parameters;

5) subsystem for representation and visualization of calculated results;

6) user interface.

All these subsystems (1)–(5) are operated through the user interface (6). The user interface also controls the output of the calculated results to the monitor, printer, and hard disk, from which they can be transmitted through communication channels to consumers of the forecast information.

2. Brief characterization of AMS subsystems

Let us characterize briefly all the AMS subsystems mentioned in Section 1.

2.1. Subsystem for processing and transformation of the input information

The subsystem for processing and transformation of the input information is an auxiliary functional module of the AMS software intended for:

1) *interactive input and decoding of aerological information* (that is, the data of temperature and wind sounding), coming in the form of KN-04 bulletins.[5] It should be noted that the procedure of processing deals not with the whole bulletin, but only with two its parts:

– TTAA, which provides for the information about the date and time of observation (00 or 12 GMT), data on the synoptic index of an aerological station, observations of pressure p (hPa) and temperature T (°C) of the air, dew-point deficit ΔT_d (°C), wind direction d (deg) and speed U (m/s) near the surface, as well as the data on geopotential H (gpm), temperature, dew-point deficit, wind direction and speed at standard isobaric surfaces: 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, and 100 hPa;

– TTBB, which contains the information about the place and time of observations and the data at the levels of singular points in the vertical temperature profiles and wind profiles;

2) *selection, transformation, and formation of aerological information in the needed forms and formats and for the information recording in the form of output files*:

– of the G type, containing the data on geopotential, temperature, dew point, zonal and meridional wind components at six standard isobaric levels: 925, 850, 700, 500, 400, and 300 hPa;

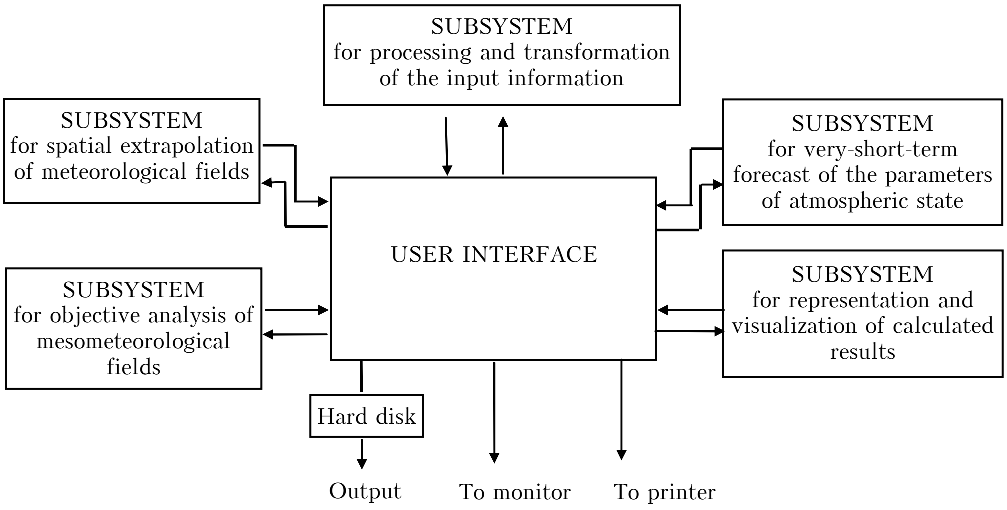


Fig. 1. Flow chart of the automated meteorological system.

– of the M type, containing the data on temperature, zonal and meridional wind components, reduced to the system of geometric altitudes: 0 (ground level), 200, 400, 800, 1200, 1600, 2000, 2400, 3000, 4000, 5000, 6000, and 8000 m;

– of the S type, containing the data on the surface and layer-average values of temperature and orthogonal wind components, calculated for the following atmospheric layers: 0–200, 0–400, 0–800, 0–1200, 0–1600, 0–2000, 0–2400, 0–3000, 0–4000, 0–5000, 0–6000, and 0–8000 m.

All the three files G, M, and S, in addition to the information mentioned above, contain supplementary data on the synoptic index of the station, its geographic coordinates and the height above the sea level, as well as on the number of bulletins from this station included in the file (it is no greater than 62, which corresponds to one month).

In addition, it should be noted that the preparation of files of the M type involves the procedure of interpolation of temperature and orthogonal wind velocity components from the standard isobaric surfaces and singular-point levels to the grid of geometric altitudes by the equation

$$\xi(h_m) = \xi(h_r) + \frac{h_m - h_r}{h_{r+1} - h_r}\left[\xi(h_{r+1}) - \xi(h_r)\right], \qquad (1)$$

where h_m is the height of an interpolation level; h_r is the height of principal isobaric surfaces and singular-point levels; r is the number of the height level.

And, finally, the preparation of files of the S type involves the procedure of calculation of layer-average values of temperature and orthogonal wind components (these parameters are widely used in military weather support and in the forecast of spatial distribution of pollutants), which is carried out, according to Ref. 6, by the equation

$$<\xi>_{h_0,h} = \frac{1}{h - h_0}\int_{h_0}^{h} \xi(z)\mathrm{d}z. \qquad (2)$$

Assuming that $h_0 = 0$ and $h = h_s$ and replacing the integral by a sum, we can write this equation in the following form

$$<\xi>_{h_s,h_0} = \sum_{i=1}^{s}\left\{\left(\frac{\xi(h_{i-1}) + \xi(h_i)}{2}\right)\left(\frac{h_i - h_{i-1}}{h_s}\right)\right\}, \qquad (3)$$

where <•> denotes the averaging of observation data over some atmospheric layer $h_s - h_0$ (here $h_0 = 0$ coincides with the ground level, h_s is the height of the top boundary of the sth atmospheric layer), and $i = 1, 2, ..., s$ is the number of the height level;

3) *search and reconstruction of missing data* on the basis of the assumption that, in reality, situations may inevitably occur, when the data from temperature and wind sounding stations contain gross errors (for example, those associated with the input of letter symbols in place of an incarnation number in a five-digit code group, with missing code group, etc.) or the data are fully absent. In such situations, it becomes necessary to reconstruct the missing information, because it is needed for the following correct operation of the algorithms of spatial and temporal prediction, which are developed on the assumption that measurements are always present for the given configuration of a local observation network and the given periodicity of observations.

Therefore, the subsystem for processing and transformation of the input information includes a software module providing for the numerical reconstruction of the missing information. The corresponding algorithm is based on the apparatus of Kalman filtering and the second-order polynomial model with polynomial coefficients varying in time (their detailed description can be found in Ref. 7).

This algorithm realizes the following sequence of actions:

– files of the G and M types are checked for the presence of information (bulletins) for the last period of measurements, that is, for the occurrence of data from the used stations;

– auxiliary diagonal matrix $\mathbf{J}_0(k)$ (where k is time) is formed (on the basis of analysis of files of G and M type), and the dimension of this matrix corresponds to the number of the stations used ($n \times n$). In the case of absence or low quality data from the ith station ($i = 1, 2, ..., n$), zero value is assigned to the corresponding diagonal element of the matrix $\mathbf{J}_0(k)$. If the data are present and contain no gross errors, then unit value is assigned;

– the data (on each meteorological parameter and every isobaric (height) level) are grouped into the measurement vector $\mathbf{Y}(k)$, where

$$\mathbf{Y}(k) = \mathbf{H}(k, x, y) \times \mathbf{X}(k) + \mathbf{E}(k). \qquad (4)$$

Here $\mathbf{H}(k, x, y)$ is the transient measurement matrix (x and y are coordinates); $\mathbf{X}(k)$ is the vector of state at time k; $\mathbf{E}(k)$ is the vector of measurement errors;

– the initial data on $\hat{\mathbf{X}}(0)$, $\mathbf{P}(0|0)$, $\mathbf{R}_\Omega$, and $\mathbf{R}_\mathrm{E}$ are defined (for the initiation of the filtering algorithm); according to Ref. 7, here $\hat{\mathbf{X}}(0)$ is the initial vector of estimation; $\mathbf{P}(0|0)$ is the initial correlation matrix of the estimation errors; $\mathbf{R}_\Omega$ and $\mathbf{R}_\mathrm{E}$ are the correlation matrices of state noise and observation noise, whose diagonal elements are, respectively, the known values of the variance of a meteorological parameters and root-mean-square (rms) errors of measurement of this parameter (they can be borrowed from Ref. 8), while the other elements are zero;

– measurements $\mathbf{Y}(k)$ are processed with the aid of the adaptive Kalman filter of the form[7]:

$$\hat{\mathbf{X}}(k) = \hat{\mathbf{X}}(k|k-1) +$$
$$+\mathbf{J}_0(k)\cdot\mathbf{G}(k)\cdot\left[\mathbf{Y}(k) - \mathbf{H}(k,x,y)\cdot\mathbf{X}(k|k-1)\right] \qquad (5)$$

(here $\hat{\mathbf{X}}(k)$ is the estimate of the vector of state at the time (k); $\hat{\mathbf{X}}(k|k-1)$ is the calculated vector of estimates predicted for the time k from the data at the time $(k-1)$; $\mathbf{G}(k)$ is the matrix of weighting coefficients). To describe $\mathbf{Y}_i(k)$, a second-order polynomial model with the coefficients varying in time is used:

$$\mathbf{Y}_i(k) = \xi_i(k) = a_0(k) + a_1(k)x_i + a_2(k)y_i + \\ + a_3(k)x_iy_i + a_4(k)x_i^2 + a_5(k)y_i^2 + \varepsilon(k),$$

where

$$|a_0(k), a_1(k), \ldots, a_5(k)|^{\mathrm{T}} = |\mathrm{X}_1(k), \mathrm{X}_2(k), \ldots, \mathrm{X}_6(k)|^{\mathrm{T}} = \mathbf{X}(k)$$

is the vector of state of a dynamic system at the kth moment in time; $\varepsilon(k)$ is the measurement error; T denotes transposition;

– the vectors $\hat{\mathbf{X}}(k)$ and covariance matrices of estimation errors $\mathbf{P}(k|k)$ are estimated for all isobaric (height) levels and meteorological parameters; the estimates are stored for the recursion use in the following iteration $(k + 1)$;

– the value of the meteorological parameter $\hat{\xi}_i$ is reconstructed as:

$$\hat{\xi}_i(k) = \hat{X}_1(k) + \hat{X}_2(k)x_1 + \hat{X}_3(k)y_i + \\ + \hat{X}_4(k)x_iy_i + \hat{X}_5(k)x_i^2 + \hat{X}_6(k)y_i^2, \quad (6)$$

where x_i, y_i are the rectangular coordinates of the ith station whose data are missing;

– the reconstructed data are arranged in the files G and M for the corresponding stations (in place of the missing data).

The general flow chart of the subsystem for processing and transformation of aerological information in the form of KN-04 bulletins is shown in Fig. 2.

2.2. Subsystem for spatial extrapolation of meteorological fields

This subsystem is one of the main AMS subsystems. It is intended for the spatial extrapolation of layer-average values of temperature and zonal and meridional wind components to a given spatial point with the coordinates (x_n, y_n) or along a trajectory of the azimuth α (deg). The extrapolation is performed with the step Δl (km) using the observations at a local network of aerological stations taken at the time of forecasting and three previous moments. In this case, it is possible to completely adjust the Kalman filter and to provide for the best quality of estimation. This subsystem serves for the meteorological support of local monitoring of anthropogenic pollution, accident prevention during take-off or landing of aircraft, etc.

The software of this subsystem is developed on the basis of the original dynamic-stochastic algorithm (its detailed description can be found in Refs. 4 and 9). Here we will mention only the basic features of this algorithm.

As the initial prognostic model, we took the few-parameter dynamic stochastic model based on equations of state in the following form:

$$\left.\begin{aligned} &\mathrm{X}_i(k+1) = \mathrm{X}_n(k)[1 - \mathrm{X}_{n+2}(k)\Delta\rho_{in}][1 - \mathrm{X}_{n+1}(k)\Delta t] + \omega_i(k), \\ &\mathrm{X}_n(k+1) = \mathrm{X}_n(k)[1 - \mathrm{X}_{n+1}(k)\Delta t] + \omega_n(k), \\ &\mathrm{X}_{n+1}(k+1) = \mathrm{X}_{n+1}(k) + \omega_{n+1}(k), \\ &\mathrm{X}_{n+2}(k+1) = \mathrm{X}_{n+2}(k) + \omega_{n+2}(k), \end{aligned}\right\} \quad (7)$$

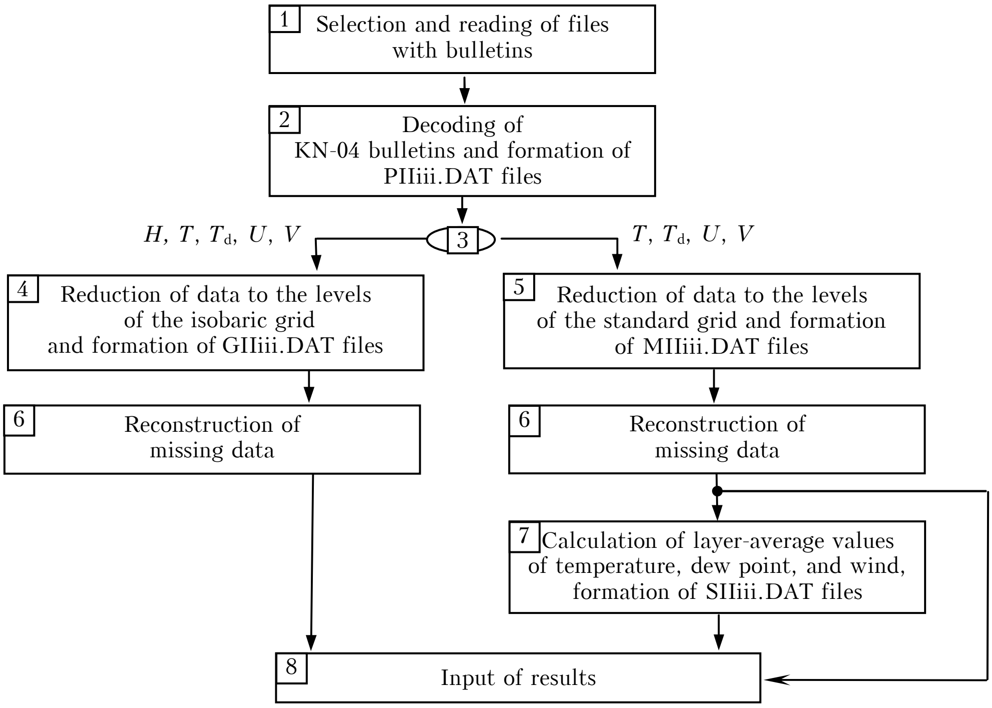


Fig. 2. Flow chart of the subsystem for processing and transformation of meteorological information.

where $X_i(k + 1)$ and $X_n(k)$ are the values of the field ξ at the ith ($i = 1, 2, \ldots, n - 1$) and nth points, lying respectively, at the territories covered and not covered by the meteorological information, at the $(k + 1)$th and kth moments in time;

$$\Delta\rho_{in} = \left[(x_n - x_i)^2 + (y_n - y_i)^2\right]^{1/2}$$

is the distance from the extrapolation point to any aerological station; $\Delta t = t_k - t_{k-1}$ is the time interval between successive measurements;

$$X_{n+1} = X_{n+1}(t) = \alpha,\ \ X_{n+2} = X_{n+2}(t) = \beta$$

are the approximating coefficients in the equations:

$$\mu_\xi(\tau) = \exp(-\alpha\tau) \text{ and } \mu_\xi(\rho) = \exp(-\beta\rho)$$

(here $\mu_\xi(\tau)$ and $\mu_\xi(\rho)$ are the temporal and spatial correlation functions; τ is the time shift, and ρ is the distance), which make up the foundation of the model (7); $\omega_1(k)$ and $\omega_n(k)$ are the random perturbations that account for the stochastic character of the model; ω_{n+1} and ω_{n+2} are the random processes of the white noise type.

Along with the equations of state of the form (7), the equation of observations was also used:

$$Y_i(k) = \xi_i(k) = X_i(k) + \varepsilon_i(k), \tag{8}$$

in which $Y_i(k) = \xi_i(k)$ is the value of the meteorological parameter at the ith point (at the ith station) at the kth moment; $\varepsilon_i(k)$ are measurement errors at the same moments.

In Eq. (8), $\xi_i(k)$ is replaced by the centered value, calculated as:

$$\xi_i(k) = \xi_i^*(k) - \bar{\xi}(k), \tag{9}$$

where $\xi_i^*(k)$ is the measured value of the meteorological parameter at the ith point and $\bar{\xi}(k)$ is the spatial (network) average value of the same meteorological parameter.

Equations (7) and (8) completely determine the structure of the estimation algorithm,[10] so the extended Kalman filter was taken as the method for synthesis of this algorithm because of nonlinearity of Eqs. (7). If Eqs. (7) and (8) are written in the matrix form, that is, as

$$\mathbf{X}(k+1) = \mathbf{\Phi}[\mathbf{X}(k)] + \mathbf{\Omega}(k); \tag{10}$$

$$\mathbf{Y}(k) = \mathbf{H}\mathbf{X}(k) + \mathbf{E}(k) \tag{11}$$

(here $\mathbf{\Phi}[\mathbf{X}(k)]$ is the transient vector-function of state; $\mathbf{\Omega}(k)$ is the vector of state noise; $\mathbf{H}$ is the matrix of observations; $\mathbf{E}(k)$ is the vector of observation noise at the kth instant), the equation of optimal estimation of the vector of state $\hat{\mathbf{X}}(k+1)$ at the time $k + 1$ has the form[4,9]:

$$\hat{\mathbf{X}}(k+1) = \hat{\mathbf{X}}(k+1|k) + \mathbf{G}(\hat{\mathbf{X}}, k+1)\cdot[\mathbf{Y}(k+1) - \mathbf{H}\hat{\mathbf{X}}(k+1|k)], \tag{12}$$

where $\hat{\mathbf{X}}(k+1|k)$ is the vector of estimates predicted for the time $(k + 1)$ from the data at the step k, and $\hat{\mathbf{X}}(k+1|k) = \mathbf{\Phi}(\hat{\mathbf{X}}(k))$; $\mathbf{G}$ is the matrix of weighting coefficients.

The calculation of the weighing coefficients $\mathbf{G}$ is described in detail in Refs. 4 and 9, and the final estimation of the meteorological parameter ξ at the extrapolation point (n) is performed by the equation

$$\hat{\xi}_n(k) = \hat{Y}_n(k) = \hat{X}_n(k) + \bar{Y}(k). \tag{13}$$

Here $\bar{Y}(k) = \bar{\xi}(k) = \sum_{i=1}^{3} q_i\xi_i \Big/ \sum_{i=1}^{3} q_i$ is the weighted mean value of the field ξ, calculated from the data of the three closest (to the extrapolation point) stations with the use of the weighting coefficients

$$q_i = 1 - \left(\rho_{in} \Big/ \sum_{i=1}^{3} \rho_{in}\right),$$

where $\rho_{in} = \sqrt{(x_i - x_n)^2 + (y_i - y_n)^2}$ is the distance to the ith station from the extrapolation point (x_n, y_n).

The general flow chart of the subsystem for spatial extrapolation of meteorological fields is shown in Fig. 3.

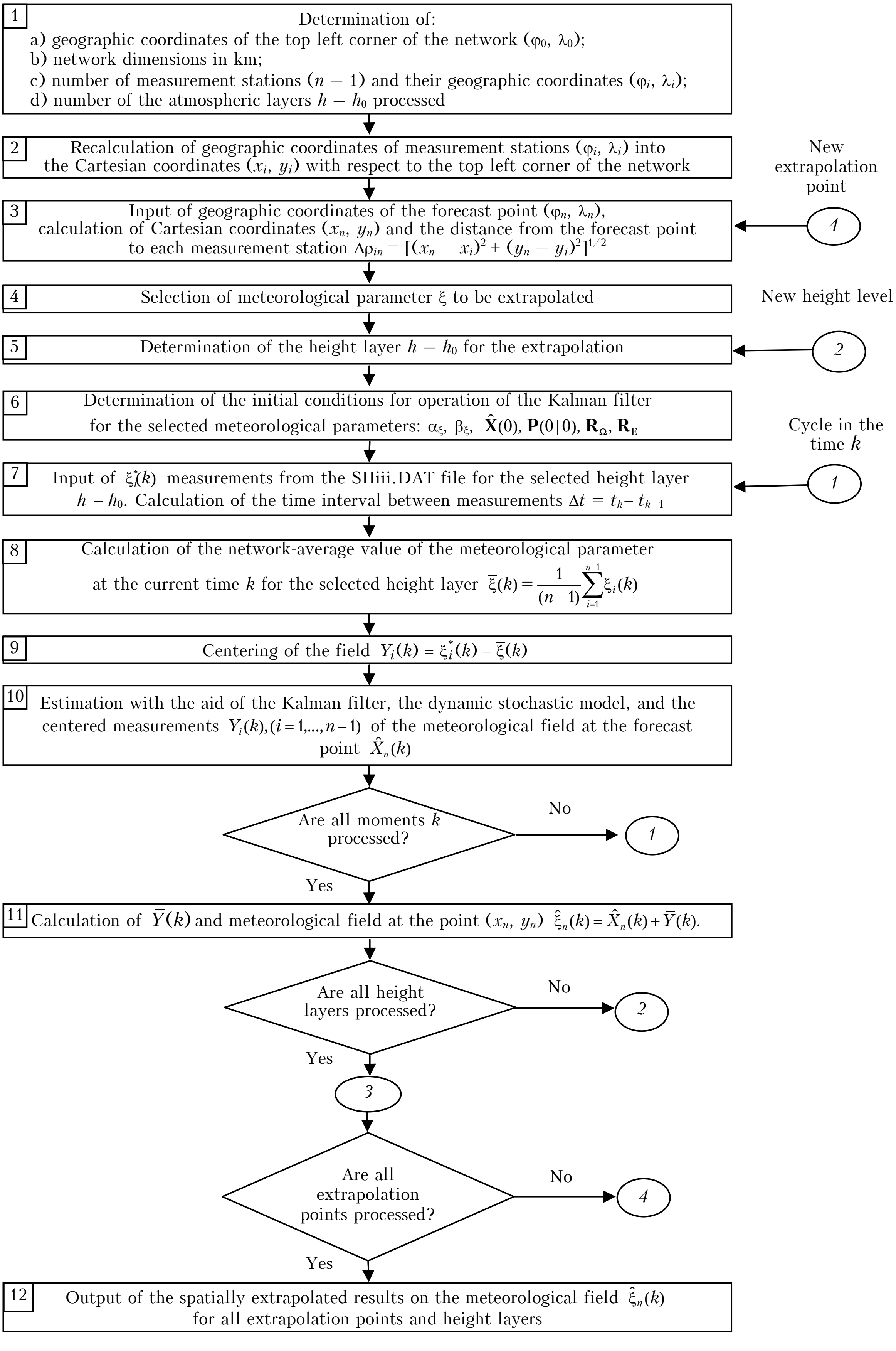
2.3. Subsystem for objective analysis of mesometeorological fields

This subsystem is the second of the main AMS subsystems, which performs the objective analysis (that is, spatial interpolation to the nodes of the regular grid) of mesometeorological fields (in our case, fields of geopotential, temperature, dew point, and orthogonal wind components). This analysis is carried out for each of the isobaric surface chosen (see Subsection 2.1) from the data of measurements of neighboring aerological stations. It is oriented at the information support of the procedure of local weather forecast using mesometeorology equations.[11]

Since the objective analysis of mesometeorological fields in the considered subsystem is carried out using the same algorithm, which is used for the spatial extrapolation, it is not considered here (its description can be found in Subsection 2.2 and in Refs. 4, 7, and 12). The main difference of the objective analysis from the spatial extrapolation is that in the objective analysis the meteorological parameter is estimated not for a point or trajectory, but at the nodes of the regular grid chosen.

2.4. Subsystem of very-short-term forecast of the parameters of atmospheric state

This subsystem is the third of the main AMS subsystems and is intended for the solution of the problem of very-short-term (with the advance time up to 6–12 h) forecast of surface and layer-average values of temperature and zonal and meridional wind components. Such results are needed, for example, for the information support of local prediction of the atmospheric pollution level.



1 Determination of:
a) geographic coordinates of the top left corner of the network (φ_0, λ_0);
b) network dimensions in km;
c) number of measurement stations ($n-1$) and their geographic coordinates (φ_i, λ_i);
d) number of the atmospheric layers $h-h_0$ processed

2 Recalculation of geographic coordinates of measurement stations (φ_i, λ_i) into the Cartesian coordinates (x_i, y_i) with respect to the top left corner of the network

3 Input of geographic coordinates of the forecast point (φ_n, λ_n), calculation of Cartesian coordinates (x_n, y_n) and the distance from the forecast point to each measurement station $\Delta\rho_{in} = [(x_n - x_i)^2 + (y_n - y_i)^2]^{1/2}$

4 Selection of meteorological parameter ξ to be extrapolated

5 Determination of the height layer $h-h_0$ for the extrapolation

6 Determination of the initial conditions for operation of the Kalman filter for the selected meteorological parameters: α_ξ, β_ξ, $\hat{\mathbf{X}}(0)$, $\mathbf{P}(0|0)$, $\mathbf{R}_\Omega$, $\mathbf{R}_\mathrm{E}$

7 Input of $\xi_i^*(k)$ measurements from the SIIiii.DAT file for the selected height layer $h-h_0$. Calculation of the time interval between measurements $\Delta t = t_k - t_{k-1}$

8 Calculation of the network-average value of the meteorological parameter at the current time k for the selected height layer $\bar{\xi}(k) = \frac{1}{(n-1)}\sum_{i=1}^{n-1}\xi_i(k)$

9 Centering of the field $Y_i(k) = \xi_i^*(k) - \bar{\xi}(k)$

10 Estimation with the aid of the Kalman filter, the dynamic-stochastic model, and the centered measurements $Y_i(k), (i = 1,\ldots,n-1)$ of the meteorological field at the forecast point $\hat{X}_n(k)$

Are all moments k processed?

11 Calculation of $\bar{Y}(k)$ and meteorological field at the point (x_n, y_n) $\hat{\xi}_n(k) = \hat{X}_n(k) + \bar{Y}(k)$.

Are all height layers processed?

Are all extrapolation points processed?

12 Output of the spatially extrapolated results on the meteorological field $\hat{\xi}_n(k)$ for all extrapolation points and height layers

Fig. 3. Flow chart of the subsystem for spatial extrapolation of meteorological fields.

The software of this subsystem is based on the original dynamic-stochastic algorithm (see Refs. 4 and 13), which employs the apparatus of Kalman filtering and a few-parameter model determined by the system of linear stochastic equations of the form:

$$\left.\begin{aligned} X_1(k+1) &= X_1(k)[1 - X_2(k)\Delta t] + \omega_1(k), \\ X_2(k+1) &= X_2(k) + \omega_2(k), \end{aligned}\right\} \qquad (14)$$

where $X_1(k)$ and $X_1(k+1)$ are the variables of state (in our case, these are the centered values of a meteorological parameter ξ^0) at the time k and $(k+1)$, and the time $(k+1)$ is the time of forecast; $X_2(k)$, $X_2(k+1)$ are the values of the approximating coefficient α and the initial autocorrelation function $\mu(\tau)=\exp(-\alpha\tau)$ (here $\alpha = 1/\tau_0$, τ_0 is the length of time correlation, τ is the advance period), taken for the derivation of the basic (first) equation of the system (14); $\Delta t = t_{k+1} - t_k$ is the time interval between successive measurements; $\omega_1(k)$, $\omega_2(k)$ are the random perturbations, that account for the stochastic character of the model (process of the white noise type).

In addition to Eqs. (14), this algorithm uses also the equation of observations:

$$Y(k) = \xi^0(k) = X_1(k) + \varepsilon(k). \qquad (15)$$

In Eq. (15), $Y(k) = \xi(k)$ are the current centered measurements of a meteorological parameter at the moment k; $\varepsilon(k)$ is the measurement error.

Equations (14) and (15) written in the matrix form

$$\left.\begin{aligned} \mathbf{X}(k+1) &= \mathbf{\Phi}(x,k) + \mathbf{\Omega}(k), \\ \mathbf{Y}(k) &= \mathbf{H}(k)\cdot X(k) + \mathbf{E}(k) \end{aligned}\right\} \qquad (16)$$

(here $\mathbf{\Phi}$ is the transient vector-function of state; $\mathbf{H} = |1 \;\; 0|$ is the transient matrix of observations; $\mathbf{\Omega}(k)$ and $\mathbf{E}(k)$ are the vectors of noise of state and observations, respectively) allow the structure of the estimation algorithm to be completely defined.[14] The filtering equation for this case is similar to Eq. (12).

Since the incoming measurements in the algorithm under consideration are first divided into the regular and centered (fluctuation) components and only the fluctuation component is predicted, the equation for the forecast of a meteorological parameter ξ has the form

$$\hat{\xi}(t_n|t_k)=\bar{\xi}(t_k)+\hat{\xi}^0(t_n|t_k)=\bar{\xi}(t_k)+[(1-\hat{X}_2(k)\Delta t_n)\cdot\hat{X}_1(k)], \qquad (17)$$

where $\hat{\xi}(t_n|t_k)$ is the forecasted value of a meteorological parameter ξ for the time t_n, obtained from the data formed by the time $t_k (t_n > t_k)$; $\bar{\xi}(t_k)$ is the time average, calculated by the time of the last measurement t_k; $\hat{\xi}^0(t_n|t_k)$ is the forecasted value of the fluctuation component at the time t_n; $\hat{X}_1(k)$ is the estimate of $\hat{\xi}^0(t_k)$, obtained with the aid of the Kalman filter at the step k; $\hat{X}_2(k)$ is the estimate of α at the step k; $\Delta t_n = (t_n - t_k)$ is the depth of forecast.

The general flow chart of the subsystem of very-short-term forecast of parameters of atmospheric state is shown in Fig. 4.

2.5. Subsystem for representation and visualization of calculated results

The subsystem for representation and visualization of calculated results is the second auxiliary subsystem, providing for execution of such operations as:

– presentation of the results of spatial extrapolation, objective analysis, and very-short-term forecast of mesometeorological fields in the tabulated and graphical forms;

– drawing of the maps of meteorological parameters in the form of isolines from the data of objective analysis of mesometeorological fields (isolines are drawn with the intervals of 1 (0.5) dkm for geopotential, 1 (0.5) °C for temperature and dew point, and 1 (0.5) m/s for the orthogonal wind components;

– sending the calculated data to the monitor, saving them in a file, or printing in the tabulated or graphical (mapped) form.

3. Software and technical characteristics of the automated meteorological system

In selecting the basic software tools used for the development of the AMS software, we took into account the possibility of their integration in the MS Windows operating system. Another aspect was the best compatibility between the software modules during the operation in the common software package.

To meet the later requirement, the development of all applications of the AMS software package was carried out in the Borland environment. The AMS Windows application was developed in the Borland Delphi 6.0, which falls in the category of the so-called Rapid Application Development (Rad) systems. This system provides for a very convenient interface, compatible with the Windows interface. A Delphi program is usually a single executable (EXE) file, which can be copied and run with the Windows OS whenever needed.

The AMS software includes the following components:

1) AIROLOG.EXE – head Windows application, realizing the AMS user interface and integrating other components into a single software package;

2) AIROLOG.HLP – help file, including the instructions for software operation;

3) AIROLOG.CNT – help topics, including all help titles;

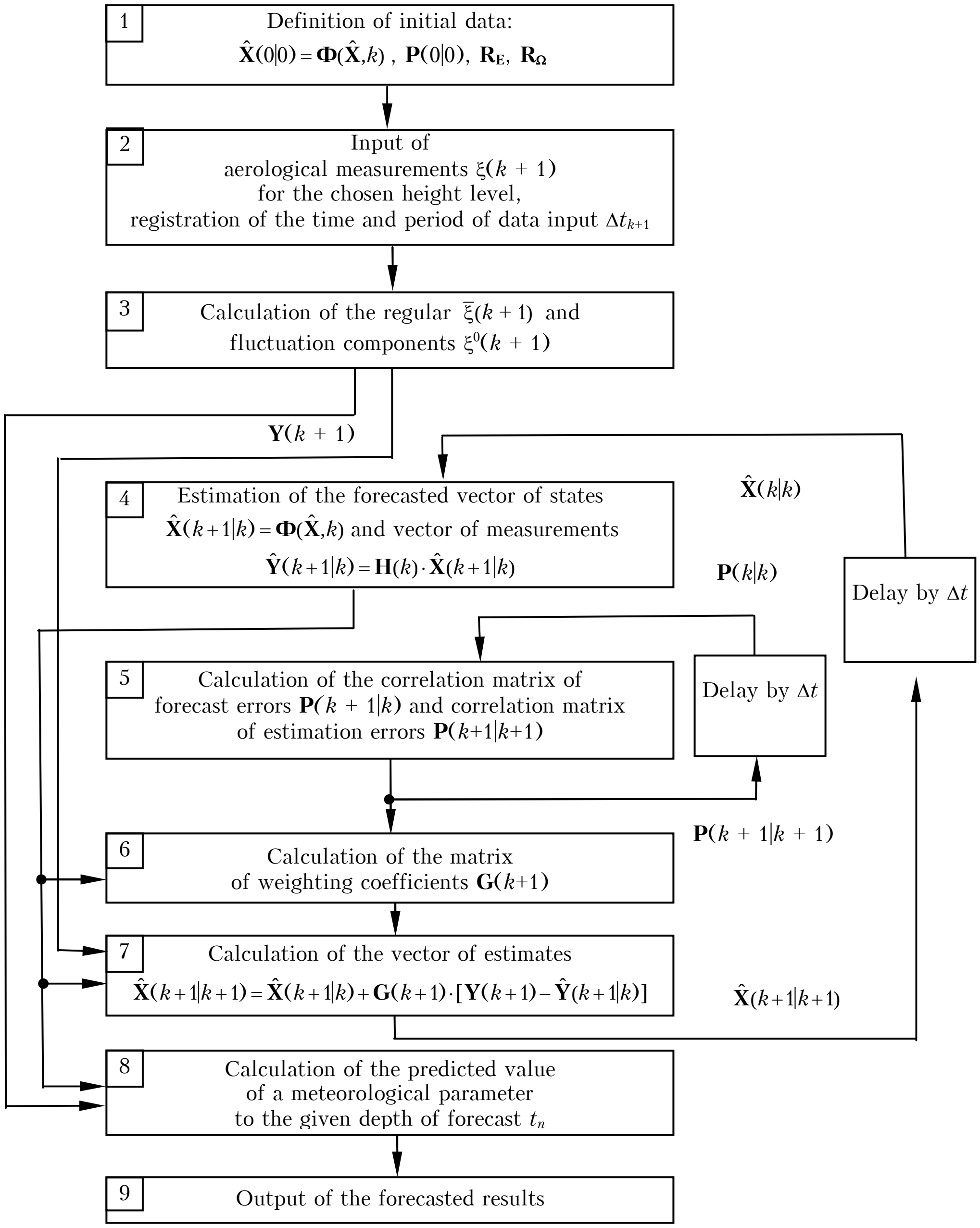


Fig. 4. Flow chart of subsystem for very-short-term forecast of the atmospheric parameters.

NORHEM.TXT – file, containing the auxiliary information about stations in the Northern Hemisphere, including synoptic indices, geographic coordinates (latitude and longitude) and height above the sea level, as well as names and home countries.

As to the technical characteristics of AMS, it is realized on the Pentium-4 personal computer with 256 Mb RAM, intended for the operation in Windows-98, 2000, XP operating systems, and allows the solution of particular problems for mesoscale networks having the size of up to 500 × 500 km under the following conditions:

– number of used aerological stations	3 and more
– spatial resolution	10–50 km
– time resolution	1–3 h
– height range	0–9 km
– minimal number of initial measurements	2–3

In conclusion, it should be noted that the efficiency of the system developed could be judged from the results of its tests. The results of such tests carried out on data of actual aerological measurements (represented in the form of standard

KN-04 bulletins), will the subject of consideration in the second part of this paper.

References

1. V.S. Komarov, *Statistics as Applied to Problems of Applied Meteorology* (SB RAS Publishing House, Tomsk, 1997), 256 pp.
2. V.S. Komarov, A.V. Kreminskii, N.Ya. Lomakina, and D.N. Khvashchevskii, Atmos. Oceanic Opt. **10**, Nos. 4–5, 343–352 (1997).
3. V.E. Zuev and V.S. Komarov, Atmos. Oceanic Opt. **13**, No. 1, 13–25 (2000).
4. V.S. Komarov, Yu.B. Popov, S.S. Suvorov, and V.A. Kurakov, *Dynamic-Stochastic Methods and Their Application in Applied Meteorology* (IAO SB RAS, Tomsk, 2004), 236 pp.
5. *KN-04 (FM-35; FM-36) Code for Transmission of the Data of Vertical Sensing of the Atmosphere* (Gidrometeoizdat, Leningrad, 1967), 31 pp.
6. V.E. Zuev and V.S. Komarov, *Statistical Models of Temperature and Gaseous Constituents of the Atmosphere* (Gidrometeoizdat, Leningrad, 1986), 264 pp.
7. V.S. Komarov, A.I. Popova, and Yu.B. Popov, Atmos. Oceanic Opt. **17**, No. 7, 500–504 (2004).
8. V.V. Reshetov, Tr. Tsentr. Aerol. Obs., Issue 133, 55–64 (1978).
9. V.E. Zuev, V.S. Komarov, S.N. Il'in, Yu.B. Popov, A.I. Popova, and S.S. Suvorov, Atmos. Oceanic Opt. **16**, No. 10, 844–849 (2003).
10. C.T. Leondes, ed., *Control and Dynamic Systems. Advances in Theory and Applications* (Academic Press. A. Subsidiary of Harcourt Brace. Jovanovich Publishers, 1976), 407 pp.
11. P.N. Belov, E.P. Borisenkov, and E.D. Panin, *Numerical Methods of Weather Forecasting* (Gidrometeoizdat, Leningrad, 1989), 376 pp.
12. V.S. Komarov, Yu.B. Popov, A.I. Popova, V.A. Kurakov, and V.V. Kurushev, Atmos. Oceanic Opt. **15**, No. 11, 915–919 (2002).
13. V.S. Komarov, S.N. Il'in, A.V. Kreminskii, N.Ya. Lomakina, G.G. Matvienko, and Yu.B. Popov, Atmos. Oceanic Opt. **16**, No. 2, 158–162 (2003).
14. V.Ya. Arsenin, *Methods of Mathematical Physics and Special Functions* (Nauka, Moscow, 1984), 383 pp.