Meteorological research at the Institute of Atmospheric Optics SB RAS since 1980 until 1999

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Results of many-year meteorological investigations carried out at the Institute of Atmospheric Optics, SB RAS in the period of 1980–1999 are described. Some problems of physical-statistical simulation of the vertical structure and composition of the atmosphere, spatiotemporal forecasting of mesometeorological fields, and compilation of databases and automated information systems are also considered in this paper.

1. Introduction

In the past decades there have appeared new research fields in the Earth's sciences, such as atmospheric optics, remote optical sensing, and environmental protection. The Institute of Atmospheric Optics takes an active part in the development of these fields. However, special applied meteorology investigations are needed to provide meteorological support for the research in these fields.

In this connection, extensive investigations in applied meteorology were initiated at the IAO in 1980. The director of the IAO, Academician V.E. Zuev has played an active part in establishing these studies. He initiated the investigations, organized the Laboratory of Physical Meteorology (LPhM), and was always the main supporter of the studies in this field.

Meteorological investigations at the Laboratory of Physical Meteorology had, among others, the following goals:

physical-statistical simulation of the vertical structure and composition of the atmosphere;

spatial and temporal forecasting of mesometeorological fields;

development of meteorological databases and automated information systems.

Investigations in the first area were started immediately after the LPhM was organized at the IAO, because the estimation of energy losses of a laser beam propagating through an air medium and solution of inverse problems of remote optical sensing, which are among the basic research fields at the IAO, require the data on distribution of physical parameters of the atmosphere (along with the optical characteristics), such as concentration of absorbing gases, air pressure and temperature. Besides, since these parameters vary widely in space and time that can hardly be taken into account, in practice it is important to have statistically reliable models of the atmosphere rather than climatic characteristics, which are usually determined from the data of individual stations and are inconvenient for use in numerical and field experiments. It was just this purpose that was stated by researchers at the LPhM.

Studies from the second research area associated with spatial and temporal forecasting of mesometeorological fields (that is, fields with the characteristic scale from tens to hundreds kilometers) started in the early 90's, when the Institute of Atmospheric Optics began the works on various problems of ecological monitoring of the atmosphere (including those using laser sensing methods). Development of the research in this new field was also favored by some projects in military geophysics the LPhM participated in. Among the problems solved in this context, the development of new and non-traditional methods of statistical reconstruction and spatial and temporal forecast of the mesometeorological fields occupies a particular place. The methods to be developed should guarantee high-quality results under conditions of minimum initial information and partial or complete uncertainty of knowledge about the structure of a simulated process and properties of noise in the data.

Research in the third field started in the mid-90's because of the need in databases and automated information systems for acquiring, processing, and displaying meteorological information and for supporting solution of various problems of atmospheric optics, laser sounding of the atmosphere, environmental protection, and military geophysics.

This paper discusses the main results obtained at the Laboratory of Physical Meteorology in the above-mentioned research fields.

2. Main results in physical-statistical simulation of structure and composition of the atmosphere

As known, in early 80's only standard and reference models of the atmosphere were most widely used in the common practice. The former ones contained only the data on the annual mean and globally averaged height distributions of air pressure, temperature, and density and had no information on the content of absorbing gases (first of all, water vapor and atmospheric ozone). The latter ones had some significant disadvantages, though included additionally the concentration profiles of the absorbing gases. Among these disadvantages, we should note the following: no information on the content of other optically active gases, zonal averaging which ignores regional peculiarities of atmospheric processes and fields, only mean profiles of physical parameters without using variability characteristics, and so on.

That is why the LPhM began the development of more complete and detailed global–regional models of the atmosphere. The models to be developed should include both zonal models for three latitudinal zones (polar, middle, and tropical) and regional ones describing the state of the atmospheric-optical channel in various regions of the Northern Hemisphere.

The procedure itself of constructing the global–regional models of the atmosphere involved three main steps that, in their turn, relate successively to stages in physical-statistical analysis of the vertical structure of meteorological fields, construction of zonal climatic models, and objective classification of climates and their model description using a few-parameter approach.

2.1. Physical-statistical analysis of the vertical structure of meteorological fields

At the first stage of constructing the global–regional models of the atmosphere, the main attention was paid to a comprehensive and detailed study of the vertical statistical structure of temperature, moisture, and ozone fields. The results of this study were generalized in three monographs.[1–3] It is worth noting here that Ref. 1 opens the series “Problems in Modern Atmospheric OpticsB written by specialists from the IAO on the initiative and under the leadership of Academician V.E. Zuev.

The monographs[1–3] give most complete and detailed information on the peculiarities of the vertical statistical structure of temperature, moisture content, and ozone fields in the atmosphere of various physical-geographical regions over the Northern Hemisphere. To obtain these data, the following sources of information were used for the first time:

– data of a wide variety of balloon-borne, ozonometric, and satellite radiometric observations;

– wide variety of statistical characteristics such as the mean values, standard deviations, correlation and autocorrelation matrices, eigenvectors and eigenvalues;

– additional (to standard ones) isobaric surfaces: 975, 950, 925, 900, 875, 825, 800, 750, 650, 600, 250, 225, and 175 hPa, which were revealed using the method of multidimensional prediction (including data on singular points); they allow adequate description of climate elements to be made in the boundary atmospheric layer (up to 1.5–2 km) and in the layers with sharp change of vertical gradients (for example, the tropopause).

All this allowed us, on the one hand, to study the climate of free atmosphere in greatest detail and, on the other hand, to obtain the reliable and sufficiently complete global information on peculiarities in the vertical statistical structure of meteorological fields under study in various physical-geographical regions of the Northern Hemisphere. This information formed the basis for constructing the zonal climatic models and solution of important practical problems associated with the objective classification of meteorological objects and development of regional models of the molecular atmosphere.

2.2. Zonal climatic models of the atmosphere

These models have earlier been described in Refs. 1–11. These include, for the first time, not only the zonal mean profiles of the altitude distribution of main optically active components of the atmosphere (pressure p, in hPa; temperature T, in K; humidity q, in g/kg; atmospheric ozone p_3, in mPa, and the content S of other absorbing gases: qn_2, qn, qm_4, N_2O, in ppm, and NO, and NO_2, in ppb) up to the altitude of 60 km with 1-km step, but also the characteristics of their variability (those are presented by the rms deviations σ). The variability characteristics were calculated for three latitudinal zones of the Northern Hemisphere: polar (90–60° N), midlatitude (60–30° N), and the tropical zone (30–0° N). It should be noted that pressure in the zonal model is presented by only the mean zonal profile because of its low variability. Besides the above-listed statistical parameters, the IAO zonal models of the atmosphere include normalized autocorrelation matrices calculated, however, only for temperature, humidity, and atmospheric ozone and covering the 0–30 km atmospheric layer (0–7 km layer for humidity).

When constructing the zonal models, we used balloon-borne, ozonometric, and satellite radiometric observations, as well as the data of rocket observations (pressure, temperature, and ozone) and specialized high-altitude measurements of the gas composition of atmospheric air. The data of specialized measurements of minor gaseous constituents of the atmosphere were borrowed from the literature (see Refs. 1 and 2 and references therein). Then, as new experimental materials were accumulated, parameters of the zonal models were refined.

The procedure of constructing zonal models was based on two approaches. Thus, to construct the mean zonal profiles of pressure, temperature, and humidity, the method of numerical interpolation was used. Within this method, climatic characteristics of stations situated in the considered latitudinal zone were first interpolated to the nodes of the 5×5° geographical grid, and then the obtained data were averaged by the equation

$$\bar{\xi}_m = \left\| \begin{array}{c} \bar{\xi}_m^{(1)} = \dfrac{1}{m}\sum\limits_{i=1}^{m} \bar{\xi}_i^{(1)} \\ \cdots\cdots\cdots\cdots\cdots \\ \bar{\xi}_m^{(k)} = \dfrac{1}{m}\sum\limits_{i=1}^{m} \bar{\xi}_i^{(k)} \end{array} \right\|, \tag{1}$$

where $\bar{\xi}_m^{(k)}$ is the area-averaged value of the meteorological quantity ξ at the level k (with $k = 1, 2, \ldots, K$) for the given latitudinal zone; $\bar{\xi}_i^{(k)}$ is the mean value of the same meteorological parameter at the level k corresponding to the ith node of the 5×5° geographical grid; m is the number of nodes that were taken in averaging.

At the same time, to construct the model covariation matrix (it includes variance), the following equation for estimation of its elements was used:

$$R^{lh} = \frac{1}{n}\sum_{i=1}^{n} R_{(i)}^{lh} - \frac{1}{n}\left(\sum_{i=1}^{n} \bar{\xi}_{(i)}^{l} \cdot \bar{\xi}_{(i)}^{h} - \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} \bar{\xi}_{(j)}^{l} \cdot \bar{\xi}_{(j)}^{h} \right), \tag{2}$$

where $R_{(i)}^{lh}$ is the covariation of the meteorological parameter calculated from the data of the sample i taken for some station and some month; $\bar{\xi}_{(i)}^{l}$ and $\bar{\xi}_{(i)}^{h}$ are the mean values of the same meteorological parameter at the levels l and h determined using data of the same sample; n is the number of statistical parameters used in calculating of the matrix $\| R^{lh} \|$.

In the case of mean concentrations of minor gases, we used, instead of Eq. (1), the following equation:

$$\bar{S}_m = \left\| \begin{array}{c} \bar{s}^{(1)} = \dfrac{1}{n_1}\sum\limits_{\mu=1}^{n_1} s_\mu^{(1)} \\ \cdots\cdots\cdots\cdots\cdots \\ \bar{s}^{(k)} = \dfrac{1}{n_k}\sum\limits_{\mu=1}^{n_k} s_\mu^{(k)} \end{array} \right\|. \tag{3}$$

Here $\bar{s}^{(k)}$ is the mean concentration of a minor gas at the level k obtained by averaging data of all observations over the concentration of this gas in the latitudinal zone; $s_\mu^{(k)}$ is the individual value of the concentration of this gas at some point of the considered zone at the level k; n_k is the number of observations at the level k.

To estimate the model values of rms deviations of the minor gas concentrations, we used the following equation:

$$\sigma_m = \left\| \begin{array}{c} \sigma^{(1)} = \sqrt{\dfrac{1}{n_1}\sum\limits_{\mu=1}^{n_1} \left(s_\mu^{(1)} - \bar{s}^{(1)} \right)^2} \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ \sigma^{(k)} = \sqrt{\dfrac{1}{n_k}\sum\limits_{\mu=1}^{n_k} \left(s_\mu^{(k)} - \bar{s}^{(k)} \right)^2} \end{array} \right\|, \tag{4}$$

where n_k is the number of observations over the content of the minor gas at the level k available in the considered latitudinal zone.

As an example, Table 1 gives an improved version of the zonal model of the atmosphere for midlatitudes in winter. Let us emphasize that because the available statistical material is too bulky, this model contains only the data on distribution of the mean values and the rms deviations of meteorological quantities.

Table 1. Zonal climatic models of the molecular atmosphere for midlatitudes of the Northern Hemisphere.

Alti-	p, hPa	T, K		q, g/kg		P_3, mPa		S_{CO_2}, ppm		S_{CO}, ppm		S_{CH_4}, ppm		S_{N_2O}, ppm		S_{NO}, ppb		S_{NO_2}, ppb	
tude, km	$\bar{p}$	$\bar{T}$	σ_T	$\bar{q}$	σ_q	$\bar{P}_3$	σ_{P_3}	$\bar{S}_{CO_2}$	$\sigma_{S_{CO_2}}$	$\bar{S}_{CO}$	$\sigma_{S_{CO}}$	$\bar{S}_{CH_4}$	$\sigma_{S_{CH_4}}$	$\bar{S}_{N_2O}$	$\sigma_{S_{N_2O}}$	$\bar{S}_{NO}$	$\sigma_{S_{NO}}$	$\bar{S}_{NO_2}$	$\sigma_{S_{NO_2}}$
0	1018	272	14.9	3.710	3.006	2.0	1.1	335	10.6	0.220	0.074	1.70	0.12	0.310	0.010	0.32	0.06	35.40	24.30
2	790	267	10.4	1.920	1.510	2.6	1.2	329	14.8	1.006	0.026	1.70	0.10	0.310	0.031	0.11	0.07	9.35	3.69
4	608	257	9.1	0.852	0.551	2.4	0.7	327	18.1	0.098	0.023	1.70	0.09	0.310	0.016	0.04	0.02	2.47	0.56
6	463	244	8.8	0.351	0.304	2.2	0.7	327	18.2	0.091	0.023	1.70	0.05	0.310	0.006	0.01	0.01	0.65	0.09
8	347	231	7.4	0.094	0.063	2.3	1.2	327	15.1	0.084	0.022	1.70	0.04	0.310	0.011	0.02	0.01	0.17	0.01
10	257	220	4.8	0.014	0.008	3.8	2.9	327	13.4	0.059	0.019	1.70	0.03	0.310	0.012	0.08	0.04	0.92	0.29
12	188	216	5.7	0.003	0.002	5.9	4.4	327	12.7	0.041	0.011	1.70	0.03	0.310	0.014	0.24	0.19	1.94	0.85
14	135	215	5.4	0.002	0.001	7.1	5.0	327	14.0	0.028	0.008	1.50	0.03	0.310	0.017	0.45	0.23	2.15	1.77
16	101	213	5.9	0.002	0.001	9.0	5.7	327	15.3	0.027	0.002	1.40	0.03	0.260	0.022	0.49	0.26	2.31	1.98
18	74	214	5.9	0.002	0.001	12.1	5.4	327	16.3	0.025	0.002	1.30	0.03	0.210	0.043	0.52	0.29	2.40	2.26
20	54	214	6.3	0.002	0.001	15.2	4.4	327	17.5	0.023	0.001	1.20	0.03	0.180	0.084	0.55	0.36	2.69	3.55
22	39	215	6.3	0.002	0.001	15.0	3.7	327	18.3	0.022	0.001	1.12	0.05	0.150	0.073	0.59	0.40	3.33	4.27
24	29	217	6.4	0.002	0.001	14.5	2.5	327	19.2	0.020	0.001	0.98	0.06	0.120	0.061	0.62	0.52	4.12	5.07
26	21	219	6.8	0.002	0.001	13.0	1.9	327	20.1	0.019	0.001	0.88	0.04	0.100	0.050	0.85	0.72	5.11	6.00
28	15	221	7.2	0.002	0.001	10.3	1.8	327	21.0	0.018	0.001	0.77	0.02	0.080	0.027	1.91	1.54	6.33	7.84
30	11	223	8.0	0.003	0.001	7.8	1.6	327	21.9	0.017	0.002	0.67	0.02	0.070	0.020	3.18	2.24	7.84	8.34
35	5.1	238	9.5	0.003	0.001	4.4	0.8	325	17.0	0.014	0.002	0.49	0.03	0.040	0.007	6.34	3.79	13.40	12.60
40	2.5	253	13.2	0.004	0.001	2.0	0.3	324	13.1	0.021	0.002	0.38	0.05	0.013	0.003	9.41	6.71	22.90	20.56
45	1.3	267	14.2	0.005	0.002	0.72	0.11	318	11.8	0.031	0.003	0.29	0.07	0.009	0.002	8.02	4.10	39.10	32.30
50	0.68	271	12.9	0.005	0.002	0.20	0.03	314	9.5	0.040	0.005	0.22	0.10	0.003	0.002	6.50	3.01	31.60	24.10
55	0.35	265	12.0	0.004	0.002	0.08	0.01	311	7.1	0.073	0.006	0.15	0.06	0.002	0.001	5.01	1.82	24.10	16.50
60	0.18	258	11.1	0.003	0.001	0.02	0.01	308	4.8	0.110	0.008	0.06	0.02	0.001	0.001	3.51	1.05	16.50	8.90

2.3. Regional statistical models of the atmosphere

According to the up-to-date concept of the meteorological support of atmospheric optics and remote optical sounding, regional statistical models of the atmosphere should be used along with the zonal ones. Regional models are based on the results of an applied objective classification of climate and climate zoning of the globe or its hemispheres. We also have used this principle in constructing regional models of the atmosphere. In contrast to traditional approaches to classification of meteorological objects that are based on application of only numerical taxonomic methods (for example, cluster analysis, factor analysis, method of principal components, and others) and ignore the physical properties of the atmosphere and principal climate-forming factors, we classify the climate of the free atmosphere (just it is considered in our case) by the system of taxonomic methods and genetic methods that are based on the mechanism of general circulation (see Refs. 1, 2, and 12).

In particular, the genetic classification is based on dividing the Earth's surface into climatic zones and regions according to the characteristics of the general circulation of the atmosphere, namely,

– zonal and meridional components of the mean wind vector,

– position of axes of the planetary high-altitude frontal zones,

– position of trade wind fronts and areas of monsoon circulation,

– position of tropospheric zones of convergence of heat and moisture fluxes,

– position of the inner tropical zone of convergence,

– position of the areas of reversal of meridional heat and moisture fluxes observed in the free atmosphere at low latitudes.

The numerical taxonomic classification was first applied to the "temperature − humidityB system[1,2] and then to the "pressure − temperature − humidity − ozone − windB system.[12,13] It employed the method of principal components (this allowed us to significantly decrease the initial index space characterizing the climate conditions in the free atmosphere) and the method of estimating the correlation between similar components on the sphere and special statistical criteria of their similarity. As these criteria we used

1) criteria of stability (similarity) of eigenvectors of the covariance matrix $\|R_{ij}\|$

$$r_{ml} = \left[\sum_{\alpha=1}^{p} r_\alpha^{ml}\,\bar{\lambda}_\alpha\right] \Big/ \sum_{\alpha=1}^{p} \bar{\lambda}_\alpha \ge r_{\text{crit}} = \tanh Z_{\text{crit}}, \quad (5)$$

where $r_\alpha^{ml} = \sum_{i=1}^{k} F_{\alpha i}^{(m)} F_{\alpha i}^{(l)} = \cos\,(F_\alpha^m, F_\alpha^l)$ is the coefficient of similarity between two eigenvectors F_α^m and F_α^l calculated for the mth and lth matrices to be compared (with $m, l = 1, 2, \dots, l$); $\bar{\lambda}_\alpha$ is the arithmetic mean of the eigenvalues of the same number α obtained for the same matrices; $p = 3$ is the number of eigenvectors taken for classification; $Z_{\text{crit}} = a\,\sigma_Z$ is the critical value of the Fisher function (here $a = 3$, $\sigma_Z = 1/\sqrt{N-3}$, where N is the sample size depending on the size of the compared matrices);

2) criterion for estimation of the significance of discrepancy between norms of the covariance matrices λ_1 (with $\alpha = 1$) based on the use of the Cochran criterion:

$$G = S_j \Big/ \sum_{m=1}^{M} S_m \le G_{0.05}(f, M), \quad (6)$$

where S_j is the largest among the M norms of the matrices compared; $G_{0.05}(f, M)$ is the critical value of the Cochran criterion taken at a 5% level of significance for the number of the degrees of freedom $f = k - 1$ (here k is the size of the empirical matrix); l is some number equal to the number of the compared matrices.

If the conditions

$$r_{ml} \ge r_{\text{crit}}, \quad G \le G_{\text{crit}}(f, M), \quad (7)$$

hold, all the compared stations are assigned to some or other quasi-homogeneous region, where the fields of variation of the meteorological parameters can be considered homogeneous in respect to the processes of global and synoptic scales.

Application of the proposed technique of objective classification of climate and climatic zoning to the Northern Hemisphere allowed us to reveal first (when only air temperature and humidity were taken as meteorological parameters) 20 quasi-homogeneous regions in winter and 17 regions in summer (the results of this zoning have been published in Refs. 1 and 2). Later on the use of the system "pressure − temperature − humidity − ozone − windB with application of the same technique allowed us to reveal already 51 quasi-homogeneous regions at the territory of the Northern Hemisphere in winter and 48 quasi-homogeneous regions in summer. The results of this climatic zoning can be found in Refs. 12 and 13. As an example, Figure 1 shows the climatic zoning of the Northern Hemisphere using the "pressure − temperature − humidity − ozone − windB system for winter.

The second important stage of statistical simulation (after classification) was the stage associated with construction of regional models of the atmosphere adequately describing the state of the atmospheric channel in the revealed quasi-homogeneous regions of the Northern Hemisphere.

Such models, as zonal ones, contain practically the same atmospheric parameters and statistics (see Refs. 13 and 14). Their only difference from zonal models is that they contain, additionally, the wind characteristics in the form of zonal (V_x) and meridional (V_y) components, and the list of minor gases includes only highly variable gases: q n , NO, and NO_2. The characteristics of these gases are included in the regional models only for those quasi-homogeneous regions, where the corresponding measurements were conducted (if no, mean zonal profiles are taken instead of the regional ones).

To obtain the mean regional profiles, we used the same averaging technique as in constructing mean zonal profiles. At the same time, the model profiles of standard deviations and correlation matrices (they were calculated only for temperature, humidity, wind, and, though in some regions, for ozone) were determined from the data of observations at reference stations situated near the center of a considered quasi-homogeneous region. Such an approach is acceptable since the vertical statistical structure of the meteorological fields studied is homogeneous within each quasi-homogeneous region revealed.

As an example, Table 2 gives the regional models of the atmosphere constructed for winter and two typical quasi-homogeneous regions of the Northern Hemisphere, namely, the regions 2.3 and 3.5 (here the first digit indicates the latitudinal zone, where 2 corresponds to the midlatitude zone and 3 corresponds to the subtropical zone, and the second digit shows the number of the quasi-homogeneous region). These regions are the European and North-American regions.

It should be noted that for brevity the autocorrelation matrices being parts of regional models are not given here (they can be found in Ref. 13).

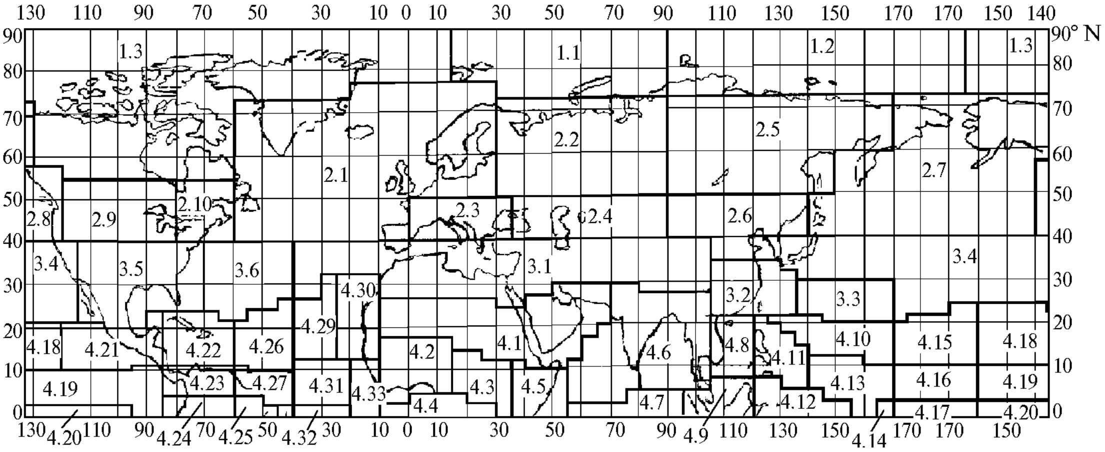

Fig. 1. Climatic zoning of the Northern Hemisphere relative to the "pressure – temperature – humidity – ozone – wind" system.

Table 2. Regional climatic models of the molecular atmosphere

Altitude, km	p, hPa	T, K		q, g/kg		P_3, hPa		S_{CO}, ppm		S_{NO}, ppb		S_{NO_2}, ppb		V_x, m/s		V_y, m/s	
	$\bar{p}$	$\bar{T}$	σ_T	$\bar{q}$	σ_q	$\bar{P}_3$	σ_{P_3}	$\bar{S}_{CO}$	$\sigma_{S_{CO}}$	$\bar{S}_{NO}$	$\sigma_{S_{NO}}$	$\bar{S}_{NO_2}$	$\sigma_{S_{NO_2}}$	$\bar{V}_x$	σ_{V_x}	$\bar{V}_y$	σ_{V_y}
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Quasi-homogeneous region 2.3 (winter)																	
0	1019	273.7	5.8	3.205	1.300	2.2	1.2	0.238	0.081	0.324	0.064	35.48	24.34	−1.1	3.0	1.6	2.5
2	798	267.4	6.6	2.747	0.821	2.8	1.1	0.145	0.026	0.108	0.070	9.40	3.61	2.2	7.0	−1.6	8.3
4	621	256.0	5.8	1.065	0.529	2.5	0.9	0.098	0.024	0.010	0.002	2.53	0.62	4.0	7.1	−3.3	9.0
6	479	242.3	5.6	0.506	0.226	2.1	0.9	0.091	0.023	0.014	0.006	0.70	0.10	8.8	8.9	−4.8	11.7
8	363	228.1	4.9	0.094	0.063	2.1	1.2	0.084	0.022	0.018	0.007	0.13	0.01	7.6	11.8	−5.4	14.7
10	269	218.1	3.4	0.014	0.008	2.7	2.1	0.059	0.020	0.022	0.013	0.30	0.04	7.8	12.2	−6.3	15.1
12	198	216.9	5.4	0.003	0.002	4.6	3.4	0.041	0.011	0.239	0.243	1.43	0.10	9.1	10.6	−6.6	12.9
14	145	216.8	3.8	0.002	0.001	5.4	4.0	0.028	0.008	0.457	0.273	2.71	0.50	10.4	7.6	−5.8	8.5
16	103	216.5	3.4	0.002	0.001	6.9	4.9	0.027	0.002	0.490	0.278	2.00	0.32	11.3	8.0	−4.8	7.8
18	74	215.4	3.4	0.002	0.002	9.8	4.7	0.025	0.001	0.522	0.290	1.48	0.20	11.7	8.3	−3.9	6.7
20	54	215.3	3.6	0.002	0.002	12.7	4.1	0.023	0.001	0.554	0.362	1.09	0.18	13.1	8.8	−3.6	6.2
22	39	215.8	3.8	0.002	0.001	14.2	2.7	0.022	0.001	0.587	0.403	0.90	0.10	14.9	10.9	−3.1	7.4
24	28	216.5	4.4	0.002	0.001	14.6	2.1	0.021	0.001	0.710	0.510	1.42	0.35	17.6	12.9	−1.8	8.7
26	21	217.6	5.3	0.002	0.001	12.5	1.9	0.019	0.001	1.800	0.720	2.75	0.81	24.6	16.0	−0.4	10.9
28	15	216.8	5.6	0.002	0.001	10.3	1.7	0.018	0.001	2.810	1.540	4.52	1.74	32.2	18.1	1.3	13.1
30	11	218.0	6.5	0.003	0.001	8.1	2.0	0.017	0.002	3.904	2.240	6.82	2.62	40.1	20.1	3.9	16.2
35	6	227.9	9.5	0.003	0.001	4.5	0.8	0.014	0.002	6.940	3.710	10.50	6.90	50.8	26.8	8.1	21.0
40	3	253.0	13.2	0.004	0.001	2.0	0.3	0.021	0.002	12.050	6.710	19.30	15.30	59.6	36.4	12.8	21.5
45	1.5	267.0	14.2	0.005	0.002	0.6	0.1	0.030	0.003	7.800	3.620	35.50	30.80	67.0	46.1	11.0	22.4
50	0.8	271.0	12.9	0.005	0.002	0.2	0.03	0.040	0.005	5.010	2.190	28.00	24.50	69.1	50.1	6.4	25.9
55	0.42	265.0	12.0	0.004	0.002	0.05	0.01	0.073	0.006	3.200	1.800	20.50	14.40	66.5	46.8	8.0	24.3
60	0.22	258.0	11.1	0.003	0.002	0.02	0.01	0.106	0.011	2.040	1.050	12.90	7.70	60.6	41.9	9.3	23.3

Table 2 (continued)

Quasi-homogeneous region 3.5 (winter)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	1020	284.2	4.2	5.630	2.200	1.5	1.0	0.240	0.074	0.336	0.068	30.20	21.90	−1.9	4.1	1.6	2.0
2	798	277.7	2.5	3.100	1.620	2.7	1.1	0.114	0.034	0.107	0.069	18.60	15.6	6.6	6.6	−1.4	7.0
4	621	266.2	2.1	1.291	0.671	2.3	0.9	0.098	0.023	0.017	0.004	11.40	9.60	8.7	6.8	−1.6	7.6
6	479	258.0	2.2	0.562	0.320	2.0	0.8	0.091	0.022	0.013	0.007	6.98	5.50	11.6	8.5	−0.5	9.1
8	363	246.4	2.3	0.094	0.063	2.0	1.2	0.084	0.022	0.017	0.007	4.28	3.22	15.3	11.7	0.9	13.4
10	269	231.3	1.9	0.016	0.009	3.0	2.6	0.059	0.019	0.022	0.013	2.63	1.86	18.2	11.3	0.9	12.7
12	198	219.8	2.7	0.004	0.002	5.1	4.2	0.041	0.011	0.130	0.024	1.61	1.08	19.8	9.0	−0.7	8.4
14	145	213.8	2.7	0.003	0.001	6.0	4.1	0.029	0.008	0.240	0.086	0.99	0.62	18.4	6.8	−1.2	7.2
16	103	211.7	2.6	0.003	0.001	7.6	4.6	0.027	0.002	0.400	0.202	0.61	0.36	15.9	6.1	−1.6	5.6
18	74	210.8	2.7	0.003	0.001	11.4	3.7	0.025	0.002	0.529	0.300	0.65	0.23	12.8	4.7	−0.6	4.1
20	54	209.7	2.7	0.003	0.001	15.0	3.4	0.023	0.001	0.702	0.302	0.78	0.30	10.3	5.6	−0.2	3.4
22	39	210.7	2.6	0.002	0.001	16.0	2.6	0.023	0.001	0.910	0.304	1.08	0.51	8.6	6.0	−0.2	3.3
24	28	213.4	2.4	0.002	0.001	15.3	2.0	0.021	0.001	1.204	0.305	1.50	0.59	8.0	6.8	0.3	3.4
26	21	216.5	2.3	0.002	0.001	12.5	1.6	0.023	0.001	2.200	0.470	2.08	0.67	10.2	7.9	1.9	3.7
28	15	219.1	2.2	0.003	0.001	10.5	1.5	0.023	0.001	3.205	1.200	3.61	0.87	13.6	11.5	2.3	4.4
30	11	224.2	3.5	0.003	0.001	7.5	1.4	0.024	0.002	4.203	2.501	4.50	2.26	17.1	16.2	4.2	5.1
35	5	241.2	4.9	0.003	0.001	4.5	0.8	0.030	0.007	6.701	4.050	9.15	4.46	20.7	20.1	6.1	5.9
40	2.5	254.2	6.2	0.004	0.001	2.0	0.3	0.033	0.009	9.010	6.800	18.5	13.8	30.3	25.3	7.2	10.3
45	1.3	264.1	6.5	0.005	0.002	0.6	0.1	0.041	0.020	7.381	4.510	34.7	29.3	35.7	29.2	9.0	14.4
50	0.7	266.2	6.6	0.005	0.002	0.2	0.03	0.080	0.063	6.910	3.000	31.2	23.70	45.8	30.0	12.2	15.6
55	0.35	261.3	6.8	0.005	0.002	0.05	0.01	0.160	0.080	3.200	2.215	19.7	12.2	57.0	32.3	11.3	17.1
60	0.18	252.9	6.7	0.004	0.001	0.02	0.01	0.300	0.110	1.800	1.205	12.1	4.50	68.7	33.1	7.4	20.2

3. Main results of the meteorological studies in statistical prediction of the mesometeorological fields

In recent years a new group of applied problems have appeared along with the problems of atmospheric optics. This group includes, first of all, the problems in ecological monitoring of the environment (these problems are associated with the evaluation and prediction of atmospheric pollution over limited territories, for example, big city, industrial region, etc.), as well as problems on geophysical information support of military operations.

For meteorological support of such problems, new methods and algorithms ought to be developed for spatial and temporal extrapolation of mesoscale meteorological fields (including extrapolation to a territory not covered by observations), since the available traditional (most often, regression) methods do not give sufficiently reliable results of such extrapolation and they cannot be used at a small bulk of experimentally measured data.

In this connection, in 1991 the IAO began large-scale fundamental and applied investigations in a new field. Let us consider some results of these investigations (the results were published in Refs. 13 and 15–26).

3.1. Technique and results of statistical altitude extrapolation of meteorological parameters

We have been solving this problem using the unique methodology based on the modified method of clustering of arguments (MMCA) (its detailed description can be found in Refs. 13 and 17).

It should be emphasized here that this method though belonging to the class of regression methods, has some significant advantages over them (as follows from Table 3).

The main idea of the MMCA is the following. Let we have a limited sample of spatiotemporal observations over a meteorological quantity in the following form:

$$\{\xi_{h,t},\ h = 0, 1, \ldots, h_k;\ \ t = 1, 2, \ldots, N\},$$
$$\{\xi_{h,t},\ h = 0, 1, \ldots, \bar{h} \le h_k;\ \ t = 1, \ldots, N + 1\}. \tag{8}$$

The mixed difference dynamic-stochastic model

$$\xi_{h,N+1} = \sum_{\tau=1}^{N^*} A_{h,\tau}\, \xi_{h,N+1-\tau} + \sum_{j=1}^{h-1} B_{h,j}\, \xi_{j,N+1} + \varepsilon_{h,N+1};$$
$$h = \bar{h} + 1, \ldots, h_k, \tag{9}$$

is used as a basis. Here h is the altitude; h_k is the maximum altitude of observations; t is the time of observations; $N = k + 1$ is the sample size, where k is the number of levels; N^* is the time lag, $N^* < (N - h - 1)/2$; $A_{h,1}, \ldots, A_{h,N^*}$ and $B_{h,0}, \ldots, B_{h,h-1}$ are unknown parameters of the model; $\varepsilon_{h,N+1}$ is the discrepancy of the model. Some set of predicting models of different structure is generated in the given class of the basis functions. Then a single model with the best structure is selected from this set. The selection algorithm of identifying the best model has been thoroughly described in Refs. 13, 17, and 26, therefore we omit its description here.

Table 3. Main differences of the MMCA from the classic regression methods

Modified MCA	Regression methods
1. Is oriented toward the use of a minimum set of real-time data ($N = k + 1$, where k is the number of atmospheric layers) and does not require pre-calculation (from the data of long-term observations) of extrapolation parameters.	1. Are oriented toward the use of a large set of long-term observations (with $N \geq 100$) and require pre-calculation (from the archived data samples) of extrapolation parameters.
2. Does not require fulfillment of the condition that the number of the initial data significantly increases the number of coefficients to be determined.	2. Require fulfillment of the condition that the number of the initial data significantly increases the number of coefficients to be determined.
3. Is based on the multi-criterion selection of the best predicting model from the set of synthesized models.	3. Are based on application of only one criterion of regularization enabling one to obtain only one model, which is not the best.
4. Is oriented toward obtaining the model of optimal complexity allowing adequate description of the structure of complex systems (including meteorological objects).	4. Use too simple models (linear or second-power), which do not provide for a proper description of complex systems.
5. Employs (along with the MCA) the method of minimax estimation of model parameters, what allows obtaining (under conditions of partial or full uncertainty of our knowledge on the structure of the simulated process and properties of noise in the initial data) of the optimal predicting model and guaranteed forecast of the state of the atmosphere.	5. Employ the method of least squares, which introduces its error (smoothing the extrema).

Let us now consider some results of the MMCA application to statistical altitude extrapolation of meteorological parameters. The first attempt to solve such a problem based on the MMCA algorithm was undertaken in 1994 (Ref. 16). However, because we had only limited experimental material, the results obtained, in spite of their acceptable accuracy, required further support based on more complete experimental data. This was done later, and the most reliable results of statistical extrapolation (reconstruction) of the profiles of meteorological parameters (using as an example temperature and wind velocity components) were published in Ref. 26. In this work, for statistical estimation of the quality of this extrapolation made with the MMCA algorithm we used the arrays of long-term (1971–1978) balloon-borne observations at five aerological stations: Warsaw (52°11′ N, 20°58′ E), Kaunas (54°53′ N, 23°23′ E), Brest (52°07′ N, 23°41′ E), Minsk (53°11′ N, 27°32′ E), and Lvov (49°49′ N, 23°51′ E).

Since the extrapolation procedure in Ref. 26 was considered as applied to the forecast of the spatial spread of a pollutant cloud, as the initial data we took the values of temperature and wind measured at the levels from h to h_0 and then averaged over the vertical, rather than the measured values themselves. Here $h_0 = 0$ corresponds to the ground level. The layer-average (or simply average) values were calculated by the equation

$$<\xi>_{h_0,h} = \frac{1}{h - h_0} \int\limits_{h_0}^{h} \xi(z)\, dz, \qquad (10)$$

where ξ is the meteorological quantity; z is the altitude, and $<\bullet>$ denotes data averaging over the vertical.

Table 4 gives the standard errors δ_ξ and probabilities p of extrapolation errors (below or above the given value) in the layer-average values of temperature and zonal and meridional wind for the stations Warsaw and Lvov. The data were obtained for some atmospheric layers and the summer, during which the correlation is weak in midlatitudes. It follows from Table 4 that the use of the MMCA algorithm for statistical extrapolation of mean temperature and mean wind components gives the results that are rather acceptable for practical use. Even for the 0–8 km layer the standard errors do not exceed 2.2–2.3° and 2.2–2.6 m/s. At the same time, for the 0–1.6 km layer, in which the main transport of technogenic pollution occurs, this error is significantly lower: only 1.2–1.3° for mean temperature and 1.9–2.2 m/s for components of the mean wind.

In conclusion, it should be noted that the MMCA algorithm was also successfully tested in solution of other problems, in particular, reconstruction of wind profiles in the boundary layer from the data of wind lidar measurements[13,22] and pre-calculation of the temperature stratification and wind in the under-cloud atmospheric layer from the data of satellite observations at the upper layers.[13,27,28]

Table 4. Standard errors (δ) and probabilities (P) of errors in extrapolation of layer-average values of temperature and zonal and meridional wind below or above the given value. Extrapolation was made by the MMCA algorithm for the stations Warsaw (1) and Lvov (2)

Layer, km	Probability, P (×10^2)										δ	
	≤ ± 1		≤ ± 2		≤ ± 3		≤ ± 4		> ± 4			
	1	2	1	2	1	2	1	2	1	2	1	2
	Temperature, °q											
0–0.2	92	90	98	100	100	100	100	100	0	0	0.6	0.6
0–0.4	90	88	96	100	98	100	100	100	0	0	0.8	0.7
0–0.8	76	64	94	92	96	100	100	100	0	0	1.0	1.1
0–1.6	56	52	86	88	96	96	100	100	0	0	1.2	1.3
0–3.0	44	48	80	76	92	90	98	97	2	3	1.6	1.7
0–5.0	40	47	75	74	90	89	96	94	4	6	1.8	2.0
0–8.0	36	44	74	73	88	86	94	91	6	9	2.2	2.3
	Zonal wind											
0–0.2	84	86	98	98	100	99	100	100	0	0	0.7	0.9
0–0.4	70	67	96	92	100	98	100	100	0	0	1.2	1.3
0–0.8	48	50	88	88	96	94	100	100	0	0	1.6	1.6
0–1.6	44	46	78	75	86	88	97	96	3	4	1.9	2.0
0–3.0	40	43	76	73	84	84	94	94	6	6	2.1	2.2
0–5.0	39	41	75	71	83	83	93	92	7	8	2.2	2.3
0–8.0	38	39	73	71	82	82	92	92	8	8	2.2	2.3
	Meridional wind											
0–0.2	96	80	100	92	100	100	100	100	0	0	0.4	0.8
0–0.4	84	72	95	88	100	100	100	100	0	0	0.9	1.0
0–0.8	78	56	84	79	100	94	100	100	0	0	1.0	1.6
0–1.6	48	48	76	76	88	85	98	92	2	8	1.7	2.2
0–3.0	44	40	74	73	85	81	95	90	5	10	2.0	2.4
0–5.0	42	38	74	72	84	81	94	89	6	11	2.1	2.6
0–8.0	40	37	73	71	82	80	93	87	7	13	2.2	2.6

3.2. Spatial extrapolation (forecast) and interpolation of mesometeorological fields

Among up-to-date and urgent problems in applied meteorology, there is a very important problem of spatial extrapolation (forecast) and interpolation of mesometeorological fields, along with the reconstruction procedure. There are two reasons for this. On the one hand, the results of spatial interpolation of such fields, especially, to a territory not covered by observations is of primary importance for meteorological support of military operations, and the results of this interpolation (basis of objective analysis) are needed for fast estimation (using the equation of pollutant transport) of pollutant spread over a limited area. On the other hand, methods of spatial interpolation and extrapolation applied in the schemes of objective analysis (for example, methods of optimal interpolation, polynomial, and spline approximation) do not give reliable results in regions with a sparse network of stations, as well as in the cases of forecast to a territory not covered by observations.

That is why the LPhM in recent years conducted a cycle of studies aimed at evaluating capabilities of the MMCA algorithm in spatial forecast and interpolation of mesometeorological fields. Since the MMCA algorithm allows only for the altitude-temporal structure of these fields in the region of a station, it was complemented by the widely used method of optimal extrapolation (interpolation). This combined technique and the corresponding algorithm are described in detail in Refs. 13, 17, 20, 23, 25, and 26, therefore we omit this description here.

Let us only remind that the method of optimal extrapolation (interpolation) reduces to determination of values of the centered field ξ at the point $\mathbf{r}_0 \notin W_x \subset R^m$ ($\mathbf{r}_0 \in W_x \subset R^m$) from its measurements at the points $\mathbf{r}_i \in W_x \subset R^m$ (here $\mathbf{r}$ is the radius vector; $i = 1, 2, \ldots, n$ is the number of points; W_x is some closed set of the finite-dimensional Euclidean space) by the equation

$$\xi(r_0) = \sum_{i=1}^{n} a_i \, \xi(r_i), \tag{11}$$

where a_i are the weighting factors.

To estimate the coefficients, the set of linear equations of the form

$$\sum_{j=1}^{n} a_j \, \mu_{ij} + a_i \, \eta^2 = \mu_{0i}, \quad i = 1, 2, \ldots, n \tag{12}$$

is used, where μ_{ij} and μ_{0i} are the values of spatial correlation functions of the meteorological parameter; $\eta^2 = \Delta^2/\sigma_\xi^2$ (Δ^2 is the variance of the measurement error, σ^2 is the variance of this parameter) is the measure of the observation error.

Note that for approximation of the spatial correlation (as applied to the ground layer, in which the extrapolation and interpolation are optimal) we proposed the following analytical functions[29]:

for temperature

$$\mu_T(\rho) = [\exp(-\alpha\rho)]\cos(\beta\rho), \tag{13}$$

for zonal and meridional wind

$$\mu_{Vx}(\rho) = \mu_{Vy}(\rho) = (1 - \alpha\rho)\exp(-\rho)^2, \tag{14}$$

where ρ is the distance, in thousand kilometers; $\alpha = 0.436$ and $\beta = 0.863$ for temperature; and $\alpha = 1.162$ for wind velocity components.

Figure 2 shows, as an example, the dependence of the rms error of the combined spatial extrapolation of layer-average temperature and wind components on the distance ρ for summer in three atmospheric layers: 0–0.4, 0–2.0, and 0–5.0 km. The extrapolation was made using the data of observations at five aerological stations, as well as the results of analogous calculations, but for shorter distances.[13] For a comparison, this figure shows the rms errors of the spatial forecast of the same parameters but using only the method of optimal extrapolation.

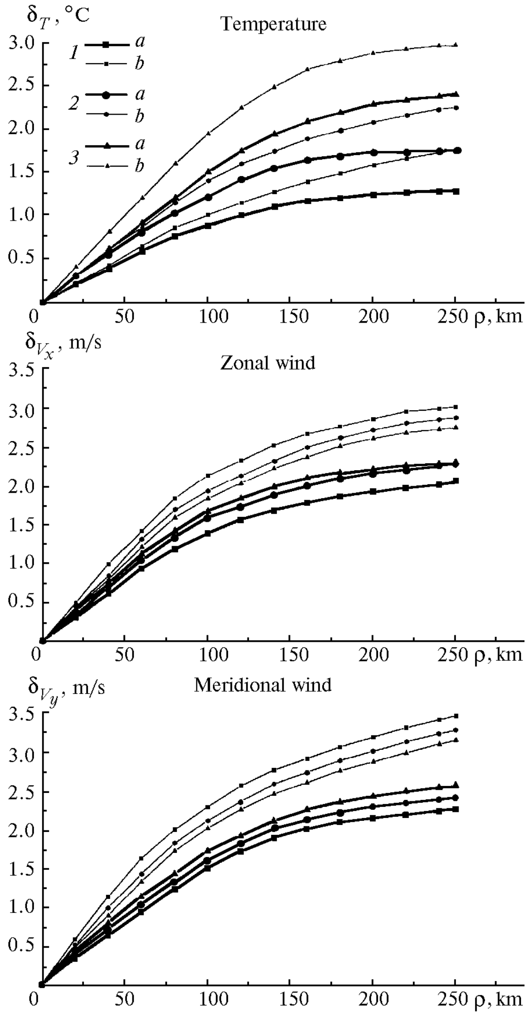

Fig. 2. Dependence of the rms error δ_ξ of the spatial forecast of layer-average values of temperature and zonal and meridional wind on the distance ρ in the layers 0–0.4 (*1*), 0–2.0 (*2*), and 0–5.0 km (*3*) with the use of the combined algorithm (*a*) and the method of optimal extrapolation (*b*).

Analysis of the obtained dependences shows that the combined algorithm gives the results acceptable for practical application, and these results are significantly better (by 25–30%) than those obtained with the use of only the method of optimal extrapolation.

The accuracy of the MMCA algorithm in objective analysis is considered in Refs. 13, 20, and 25.

3.3. Ultra-short-term forecast of vertical profiles of zonal and meridional wind

Along with the spatial extrapolation, the MMCA algorithm was also tested in ultra-short-term (for the term up to 12 hour) forecasting of layer-average values of wind components in the boundary atmospheric layer, since the data on these parameters are needed for pre-calculation of possible changes of pollution over a limited area (for example, an industrial center or a big city).

This forecast, as the spatial one, was based on combination of two methods, namely, the method of optimal extrapolation of a random process and the MMCA. The detailed description of this procedure and results of its application to this problem can be found in Refs. 21 and 22.

Let us only emphasize that the method of optimal extrapolation of a random process used for pre-calculation of the surface wind components at the time $t + \tau$ (τ is the lead time of the forecast) is based on the equation in the following form:

$$\hat{\xi}(t + \tau) = \bar{\xi} + \sum_{k=0}^{n} a_k\, \xi'(t - k), \tag{15}$$

where $\bar{\xi}$ is the norm (for a stationary process $\bar{\xi}(t) = \bar{\xi} = \text{const}$); $\xi'(t - k)$ is the deviation of the meteorological parameter from the norm at the previous moments in time $t - k$ ($k = 0, 1, 2, \ldots, n$); a_k are some weighting factors determined from solution of the set of linear equations

$$\sum_{j=0}^{n} a_j\, \mu_\xi(k - j) = \mu_\xi(t + k), \quad k = 0, 1, 2, \ldots, n. \tag{16}$$

In Eq. (16) μ_ξ is the normalized correlation function calculated using the proposed analytical approximation[21]:

$$\mu_{V_x}(\tau) = \mu_{V_y}(\tau) = \exp[-\alpha(\tau)], \tag{17}$$

where $\alpha = 0.275$ for the zonal wind and 0.537 for the meridional wind.

Numerical experiments were conducted with the data of measurements performed with a three-path correlation lidar at 2, 6, 10, 14, 18, and 22 hours of local time. The data were obtained in Tomsk (56° N, 85° E) in the period since June 10 until August 12, 1994. As the results of numerical experiments showed, the accuracy of the ultra-short-term forecast made with the use of the combined algorithm is acceptable for practice (especially for $\tau = 4$ hours, for which the rms errors vary in the entire boundary layer within 0.6–2 m/s).

4. Results of meteorological investigations aimed at compilation of meteorological databases and automated information systems

As known, automation not only provides for entering, processing, and storage of bulky experimental information on a computer, but also makes it possible to operatively solve some complicated mathematical problems, including the forecasting problems.

That is why in 1992 the LPhM started extensive studies on compilation of meteorological databases and development of automated systems for processing and displaying meteorological information. Let us consider briefly the results obtained (these are fully presented in Refs. 30–32).

4.1. Database of regional climatic models of the molecular atmosphere

Compilation of the database of regional models of the molecular atmosphere was the first result the LPhM obtained in the field of automation. This database was compiled for fast invoking the regional models in design and flight tests of space-based instrumentation, estimation of the influence of air medium on the optical radiation transfer, interpretation of satellite measurements and lidar data, etc. The database of regional models is intended for:

- systematization and optimal organization of storage and access to regional models of the molecular atmosphere;
- search for a model corresponding to a user's query;
- presentation of model characteristics in the tabulated form;
- export of parameters of the required model in automated systems of different purpose (for example, systems for meteorological support of local-regional monitoring of atmospheric pollution[31]).

Note that we do not describe here the models of the molecular atmosphere included in the database, since these have been considered above.

The database of regional models was designed in accordance with the well known DATAID–1 methodology (it is described in Ref. 30). As an example, Fig. 3 shows the global operating scheme of the database of regional models of the molecular atmosphere.

The spatial organization of this database is the set of statistical characteristics of meteorological parameters being parts of regional models and corresponding to one of the revealed quasi-homogeneous regions of the Northern Hemisphere, each described by ordered geographical coordinates of its nodes accurate to 2.5°.

A required regional model is selected by the set of search elements: season, geographical coordinates, meteorological parameter, and statistical parameter.

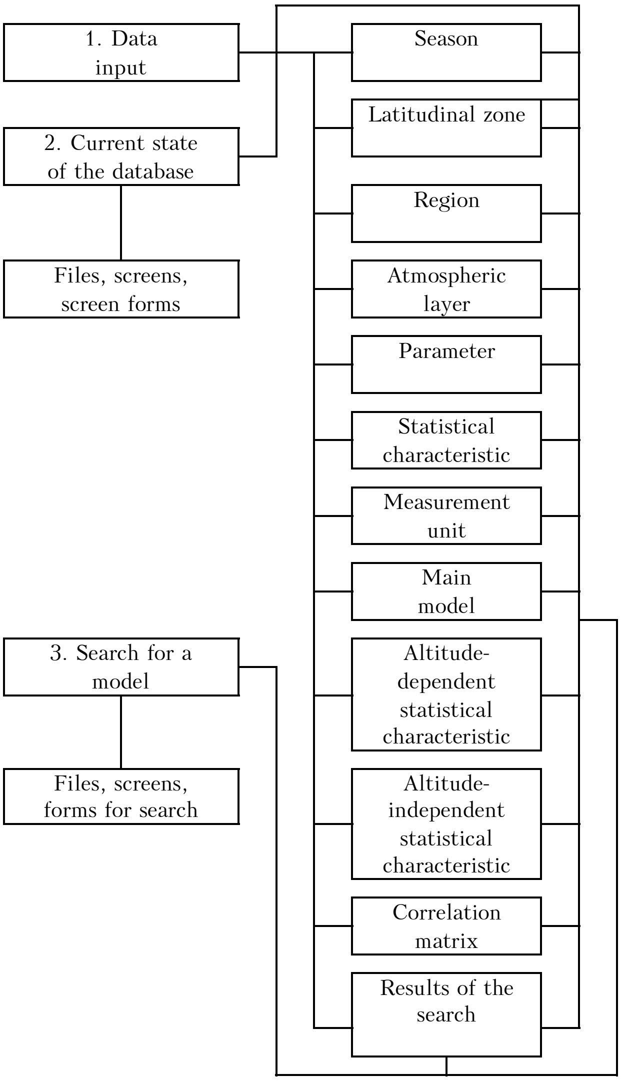

Fig. 3. Global operating scheme of the database of regional models.

The database of regional models of the molecular atmosphere was developed in Paradox 4.0 by Borland Inc.

In addition to the above-described database, in most recent years the LPhM has started development of the database of regional models of the boundary atmospheric layer. This database includes the parameters of these models in the form of model profiles of the mean values and rms deviations of pressure, temperature, humidity, and wind velocity components up to the altitude of 2 km, as well as the corresponding autocorrelation matrices.

The regional models of the boundary atmospheric layer are constructed for winter and summer in the system of geometrical altitudes including such levels as 0 (Earth's surface), 100, 200, 300, 400, 600, 800, 1200, 1600, and 2000 m.

This database is designed following the same methodology as in design of the database of regional models of the molecular atmosphere (for details see Ref. 32).

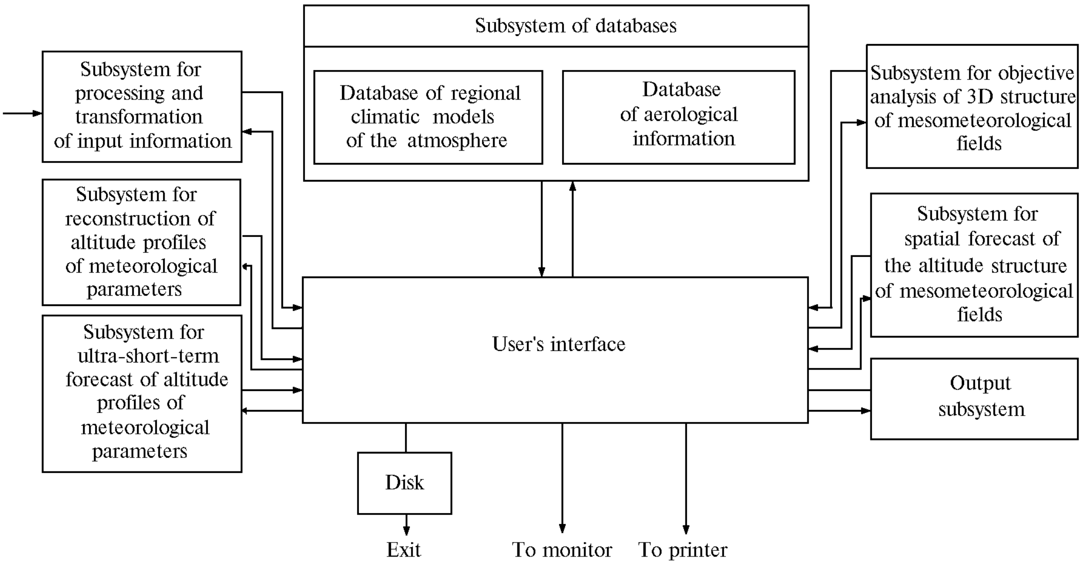

Fig. 4. Block-diagram of a Geofizik automated workplace.

4.2. Automated information systems

In 1995 the LPhM began studies aimed at development of automated information systems for meteorological support of applied problems. By now the first version of this system has been developed. One its variant is thoroughly described in Ref. 31 as applied to meteorological support of local-regional monitoring of atmospheric pollution.

Below we consider the general and multi-purpose variant of the automated system, which employs all the above-described algorithms of spatial and temporal forecast of mesometeorological fields.

This system in the form of automated geophysicist's workplace was developed as a multi-purpose and professional computer system.

Figure 4 shows the general configuration of the system, which includes seven subsystems and user's interface.

Let us characterize briefly each subsystem.

1. *Subsystem of databases* is intended for support of solution of the main problems associated with numerical forecast of mesometeorological fields in space and time. It includes two databases:

– database of regional climatic models of the atmosphere containing model profiles of the mean values (norms) and rms deviations of temperature and zonal and meridional wind up to the altitude of 30 km for quasi-homogeneous regions of the Northern Hemisphere revealed from objective classification of climates of the free atmosphere (the technique and results of this classification are considered above);

– database of routine aerological information for systematization, storage, and formation of archives of routine data coming in the form of METEO–11 bulletin (it contains the data on layer-average values of temperature and wind characteristics), as well as archives of generalized data presented by station norms and rms deviations of these meteorological quantities.

2. *Subsystem for processing and transformation of input data* is intended for interactive input of aerological information coming in the form of METEO–11 bulletins, selection of the needed data, and their transformation into the given format.

3. *Subsystem for reconstruction of altitude profiles of meteorological parameters* is intended for numerical reconstruction of the layer-average values of temperature and zonal and meridional wind from the surface data and earlier observations.

4. *Subsystem for ultra-short-term forecast of altitude profiles of meteorological parameters* is intended for ultra-short-term forecast (for the term up to 6 hours) of the mean temperature and zonal and meridional components of the mean wind in the region of an aerological station.

5. *Subsystem for a spatial forecast of the altitude structure of mesometeorological fields* is intended for spatial extrapolation of mesoscale fields of temperature and wind to a territory not covered by observations (at the distance up to 250 km). This problem is solved with the use of two algorithms.

The first algorithm is applied if the number of altitude observations $N < k + 1$ (here k is the number of levels or layers of the atmosphere). In this case the method of optimal extrapolation is used for spatial forecast. The second algorithm is invoked if the number of observations $N \geq k + 1$, therefore it is based on the procedure combining the method of optimal extrapolation and the MMCA.

Both algorithms include the procedure for introducing corrections for terrain effects to the extrapolated values.

6. *Subsystem for objective analysis of the 3D structure of mesometeorological fields* is intended to

determine vertical profiles of meteorological parameters at the nodes of a given mesoscale grid from the data of aerological observations at neighboring stations. The procedure of objective analysis is based on the use of the MMCA and the method of optimal interpolation, if the grid node falls in the region of interpolation, and the method of optimal extrapolation, if it is beyond this region.

7. *Output subsystem* records (in the given format) the calculated results and displays them, prints out, or saves in a file.

8. *User's interface* provides for operation of all the subsystems. Each subsystem can be run from the user's interface.

The user's interface is realized as Windows 3.1 application ARM.EXE. The system was developed to operate in the Delphy environment. This environment includes the high-level programming language Object Pascal, which allows calling external functions in the C style and invoking programs in any of wide-spread programming languages (in our case, it is FORTRAN, which was used in the main programs for forecast).

The first version of the system was implemented on PC/AT 386.DX with 4 Mb RAM and 80 Mb free space on a hard disk.

5. Conclusion

This review generalizes only most important results of meteorological investigations at the IAO obtained since 1980 until 1999. However, the scope of the problems solved at the LPhM is much wider, in particular,

– the techniques and algorithms developed for numerical forecast of the characteristics of the atmospheric-optical channel; these are based on the method of clustering of arguments and the data of expanding vertical profiles of meteorological parameters[33] into a series over empirical orthogonal components (EOC);

– the methodology was proposed for organization of municipal and regional geoinformation systems for monitoring of atmospheric pollution[34,35];

– the spatial statistical structure of the cloud field was studied and the probability of favorable and unfavorable cloudiness conditions was evaluated as applied to functioning of spaceborne observation systems[36,37];

– the vertical structure of the field of stratospheric ozone over the Western Siberia was climatically analyzed and one of the mechanisms of formation of its interannual variability was proposed; this mechanism is connected with atmospheric circulation varying from year to year.[38, 39]

The further development of meteorological investigations is directed toward studying the dynamics of the boundary atmospheric layer and temporal variability of the regional climate of the Western Siberia and analyzing the spatiotemporal structure of mesometeorological fields, in particular, the fields of geopotential, temperature, humidity, wind, etc. Besides, much attention will be paid to further development of the methods and algorithms of numerical estimation of current and expected meteorological conditions at territories not covered by observations. The development of automated information systems will be continued taking into account the geoinformation technology and new methods of forecast of high-altitude meteorological fields.

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