PROBLEM OF THE OPTIMAL ARRANGEMENT OF A NETWORK OF METEOROLOGICAL STATIONS FOR OBJECTIVE ANALYSIS OF 3-D MESOMETEOROLOGICAL FIELDS

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We discuss here an approach to proper arrangement of a network of aerological stations, enabling objective analysis of 3-D mesometeorological fields. Numerical calculations show that for a typical mesometeorological polygon the maximum admissible spacing between stations, $l_{\max,}$, *is* 120 km *for temperature and about* 60 km *for wind velocity components.*

The problem of objective analysis of the 3-D mesometeorological fields (i.e. fields with horizontal scale on the order of tens to hundreds of kilometers[1]) recently attracted much attention, particularly, with the advent of modern remote lidar sensing systems enabling estimation of atmospheric structure and composition (in the boundary layer, particularly) to a high time and spatial resolution unattainable with radiosonde systems. Such a capability is much needed for objective analysis of meteorological fields, used for numerical prediction of the mesometeorological processes evolution and local weather forecast (with the help of mesometeorology equations), as well as for local diagnostics and prediction of pollutants dispersion over local areas.

The success of objective analysis of 3-D mesometeorological fields depends very much on the arrangement of the aerologic stations network, that must satisfy the following two requirements:

– first, aerological (including lidar) stations must be arranged so that the errors in vertical profiles of meteorological parameters (such as geopotential, temperature, wind), when reconstructed using data from stations available, are in each node of a grid less than a preset value (defined by the requirements of the problem to be solved);

– second, the number of stations providing data for objective analysis must be minimized and the stations should be as close to the regular network nodes used as possible.

From the above criteria, the problem of optimal arrangement of aerologic stations is in fact reduced to the determination of a maximum admissible distance between the stations located on the mesometeorological polygon under study, sufficient for estimating (to a required accuracy) of the meteorological parameters sought at all nodes of the chosen regular grid within this polygon.

Here we have to emphasize one important point. In contrast to a well studied problem of optimal arrangement of meteorological and aerological networks[2] enabling objective analysis of macroscale fields, similar aspects of the problem in the case with mesoscale fields are still unclear.

Taking into account all the aforesaid we have tried to construct a special algorithm for solving the problem on optimal arrangement of aerological network to enable objective analysis of mesometeorological fields.

In this paper we discuss this algorithm and some results of its approbation using the data on temperature and wind as an example. The material used for this was the experimental data from the six aerologic stations forming typical mesometeorological polygon (mapped on Fig. 1) located in the West Ukraine and Byelorussia. The used aerologic observations analyzed spanned from November 24 till December 7, 1991. The data of these observations have been reduced to a certain scale of geometrical altitudes (0, 0.1, 0.2, 0.4, 0.8, 1.2, 1.6, 2.0, 3.0, 4.0, 5.0, 6.0, and 8.0 km) that allowed the description of the temperature and wind vertical structures through the entire troposphere.

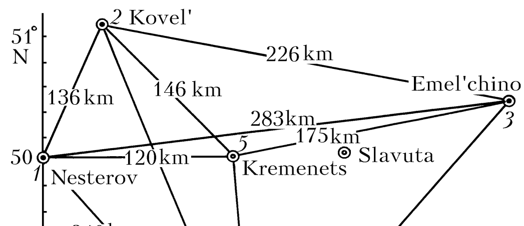

FIG. 1. Scheme of a typical mesometeorological polygon.

We should note from the very beginning that the complete set of tropospheric levels was used at the preliminary stage only to estimate the spatial variations in near-ground and boundary-layer temperature and wind velocity components, as well as these in the free

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atmosphere. The spatial variability of mean values of the meteorological parameters chosen was inspected and found to be maximum in the near ground layer. From this fact, as well as based on analogous results obtained earlier for spatial correlation functions of temperature and wind (see, e.g., Ref. 2), only near-surface values were used to determine the maximum admissible spacing between stations.

Now we should like to consider the algorithm we use to solve the problem on optimal arrangement of sounding stations required for an objective analysis of the mesometeorological fields. This algorithm is based on the simplest quantitative approach to the problem on proper arrangement, first introduced by Drozdov and Shepelevskii[3] and Drozdov,[4] consisting in the evaluation of the rms error in the linear interpolation of meteorological parameter to the midway point between two neighboring sites. Since the midway point linear interpolation obviously has the largest rms error $E_{2\Lambda}$, the authors of Refs. 3 and 4 have chosen just this error as a criterion in the network arrangement. In such a case the interpolation procedure is simply the arithmetic mean of two neighboring site values.

If the field of meteorological parameter under consideration is homogeneous and isotropic with respect to its spatial correlation function $\mu(l)$, which is quite a natural assumption for a mesometeorological polygon, and provided that the variable itself is measured with a random error, the measure of the interpolation error $\varepsilon^2_{2\Lambda}$ (where $\varepsilon^2 = E^2/\sigma^2$ with σ^2 being the variance of the meteorological parameter) can be estimated by a simple formula[4]

$$\varepsilon^2_{2\Lambda}\,(l) = \frac{3}{2} - 2\mu(l/2) + \frac{1}{2}\,\mu(l) + \frac{1}{2}\,\eta^2, \tag{1}$$

where l is the distance between stations; $\mu(l)$ is the spatial correlation function of a meteorological parameter; and $\eta^2 = \Delta^2/\sigma^2$ is the so-called measure of measurement error (here Δ^2 is the variance of the observation error, and σ^2 is the variance of the meteorological parameter).

By calculating the correlation function of a meteorological parameter under consideration, e.g., via some analytical formula of the form:
for temperature[7]

$$\mu_T(l) = \exp(-0.825 l^{0.92}), \tag{2}$$

and for wind velocity components[8]

$$\mu_U(l) = \mu_V(l) = (1 - 0.98l)\exp(-0.98l), \tag{3}$$

and having known the variance of measurement error, from formula (1) one then easily find the maximum permissible spacing l, i.e., the distance at which the midway point interpolation error would be some preset value. This value is proposed in Refs. 3 and 4 to be, in particular,

$$\varepsilon = \eta, \tag{4}$$

which in other words is the requirement that the interpolation error coincides with the error of measuring the meteorological parameter.

Summarizing we should like to note that the choice of maximum permissible spacing was made in a way different from that in Refs. 3 and 4. In particular, formula (1) uses not the measure of measurement errors, η^2, but the measure of admissible errors

$$\eta_a^2 = \delta^2/\sigma^2, \tag{5}$$

where δ^2 is the variance of the admissible error in the estimate of the meteorological parameter, σ^2 is the variance of this parameter. This is because typically δ^2 is larger than Δ^2 (e.g., the accuracy of temperature measurement, in terms of standard deviation Δ_T, is on the order of 0.7 K in the lower troposphere,[5] while the corresponding error δ_T committed by the World Meteorological Organization is 1 K (Ref. 6).

Furthermore, η in formula (2) is replaced by the minimum value η_{min} of all η values calculated for each of the six stations of mesometeorological polygon with the regard for standard measurement error of meteorological parameter.

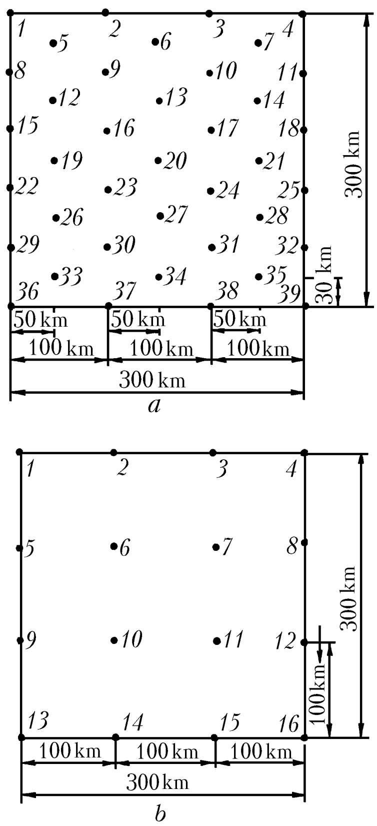

FIG. 2. Scheme of the mesometeorological polygon arrangement.

Let us now discuss the results of numerical estimation of maximum permissible spacing between stations (Fig. 2) located within the mesometeorological polygon under consideration. Table I lists, for all stations within the polygon, values of standard (rms) deviations σ as well as the admissible errors η_a calculated using data from ground measurements of temperature (T, °C), zonal (U, m·s^{-1}) and meridional (V, m·s^{-1}) wind velocity components, with η_a, estimation made by formula (3).

TABLE I. The rms deviations (σ) and the measure of measurement error (η) for temperature (T), zonal (U) and meridional (V) wind velocity components, for typical stations of a mesometeorological polygon.

Station	*T*		*U*		*V*	
	σ	η	σ	η	σ	η
Nesterov	4.0	0.090	2.3	0.272	1.4	0.735
Kovel'	4.3	0.078	1.7	0.498	1.4	0.735
Kremenets	4.4	0.075	2.3	0.272	1.4	0.735
Emel'chino	3.9	0.095	2.3	0.272	1.5	0.64
Chernovtsy	3.7	0.105	2.2	0.298	1.6	0.563
Slavuta	4.2	0.085	2.3	0.280	1.4	0.695

From Table I we clearly see that the mesometeorological polygon studied, despite its small area (see Fig. 1), is characterized by markedly varying σ and η_a over space, especially, for the temperature and zonal wind fields. That is why we took into account spatial variations of these parameters when determining the measure of interpolation error $\varepsilon^2_{2\Lambda}$ and the station-to-station spacing l_{max}, which was calculated by formula (1) for all possible station spacing and is given in Table II. Note that the standard interpolation errors ε^2_{2a}, rather than $\varepsilon^2_{2\Lambda}$, are given in Table II, while its first line contains values of this error calculated by formula (1) for fixed station-to-station spacing of 30 km.

From Table II we can see that the maximum permissible distance l_{max} for stations of the chosen mesometeorological polygon (provided that ε is equal to η_{min} specified by Table I) is 120 km for temperature and about 60 km for wind velocity components. This means that an optimal arrangement of the aerological network (including lidar stations) over mesometeorological polygons requires that maximum separations l_{max} between stations does not exceed 60 km. Then, the main criteria of the objective analysis of a three-dimensional structure of the mesometeorological fields (particularly, the requirement of a minimum interpolation errors), conducted for the temperature–wind complex, are met.

In conclusion, we consider typical scheme of an optimal arrangement of radiometeorological (or lidar) stations over the territory of a typical mesometeorological polygon having horizontal size about 300 km and area of 300×300 km, coinciding with the area of a grid cell in a large-scale global model (1) used for numerical weather forecast. That scheme is presented in Fig. 2*a* from which we conclude that most successful objective analysis of the three-dimensional temperature and wind fields, performed on a typical mesometeorological polygon, is achieved having about 39 high-altitude sensing stations within this polygon. This will allow the spatial interpolation (extrapolation) of the vertical structure of temperature and wind fields to be performed with minimum errors at all the tropospheric levels chosen, an underlying surface inclusive.

TABLE II. Values of the interpolation error measure (ε) versus station-to-station separation (l_{max}).

T		*U*		*V*	
ε	l_{max}	ε	l_{max}	ε	l_{max}
0.0744	60	0.2706	60	0.5735	60
0.0751	120	0.3630	120	0.6225	120
0.0755	136	0.3839	136	0.6348	136
0.0757	146	0.3963	146	0.6424	146
0.0768	175	0.4303	175	0.6640	175
0.0778	198	0.4554	198	0.6805	198
0.0795	226	0.4840	226	0.7000	226
0.0804	240	0.4977	240	0.7095	240
0.0839	283	0.5373	283	0.7378	283
0.0871	316	0.5655	316	0.7586	316

Somewhat different scheme of the aerologic network arrangement can be accepted when an average over all η presented in Table I is used instead of η_{min} to estimate maximum permissible distance l_{max}. The maximum permissible distance l_{max} for the temperature–wind complex is now about 100 km, with the number of required stations reduced to 16.

Of course, these conclusions need to be confirmed by data from other polygons as well as to be tested against a more complete statistical material.

REFERENCES

1. P.N. Belov, E.P. Borisenkov, and B.D. Panin, *Methods of Numerical Weather Forecast* (Gidrometeoizdat, Leningrad, 1989), 376 pp.
2. L.S. Gandin and R.L. Kagan, *Statistical Methods for Interpretation of Meteorological Data* (Gidrometeoizdat, Leningrad, 1976), 359 pp.
3. O.A. Drozdov and A.A. Shepelevskii, Trudy NIU GUGMS, Ser. 16, No. 13, 5–115 (1946).
4. O.A. Drozdov, Trudy Gl. Geofiz. Obs., No. 123, 33–46 (1961).
5. V.D. Reshetov, Trudy Tsentr. Aerolog. Obs., No. 133, 55–64 (1978).
6. *Technical Regulations*. VI (General Part) 2-nd edition, WMO, No. 49, OD.2, Geneva (1959. Supplement No. 2, Geneva (1963).
7. D.I. Kazakevich, *Foundations of the Theory of Random Functions and Their Applications in Hydrometeorology* (Gidrometeoizdat, Leningrad, 1977), 319 pp.
8. Yu.M. Liberman, in: *Proceedings of the III All-Union Symposium on Applications of Statistical Methods in Meteorology* (Gidrometeoizdat, Moscow, 1978), pp. 162–165.