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Abstract

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ANALYSIS OF METEOROLOGICAL AND AEROLOGICAL DATA WITH THE AID OF AN ELECTRONIC COMPUTER

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In papers ([1−3]) a method was developed for objective, machine analysis of data from meteorological and aerological observations, and examples of calculations were given. In the present article some results are set forth on the construction and testing of a scheme of objective analysis that gives sufficient accuracy and is suitable for operational use in compiling numerical (hydrodynamic) weather forecasts. As in ([1,3]), from data on geopotential heights and wind one seeks the best surface approximating the isobaric surface over a bounded territory. However, in contrast to those papers, the indicated approximation is performed by a polynomial of the third degree, rather than of the second. Another difference from the scheme adopted in paper ([1]) consists in allowing for a weight factor, which depends on the distance from the station to the grid point and is introduced in order to obtain the best approximation at the point itself. Finally, we abandoned the use of numerical-forecast data, employed in paper ([3]) and important for analysis in regions with an insufficiently dense network of stations. The increased reliability of the analysis in these regions was ensured by choosing the most advantageous sequence of computation, in which, for each grid point, in addition to direct observations, data from the maximum number of nearest previously analyzed points are used.

The problem of determining the value of the geopotential height at a certain grid point, solved by the method of least squares, reduces to finding the minimum of the function S:

$$S = \sum_{n=1}^{N} p_n \left[\sum_{i+j=0}^{3} a_{ij} x_n^i y_n^j - H_n \right]^2 + q \frac{g^2}{l^2} \sum_{m=1}^{M} p_m \left\{ \left[\sum_{i+j=1}^{3} i a_{ij} x_m^{i-1} y_m^j - \frac{l}{g} v_m \right]^2 + \left[\sum_{i+j=1}^{3} j a_{ij} x_m^i y_m^{j-1} + \frac{l}{g} u_m \right]^2 \right\}. \quad (1)$$

Fig. 1

Figure 1: Fig. 1

Here M and N are the number of stations in the neighborhood of the computed point of radius R (in units of the grid step) that have provided information on the wind and on the height of the isobaric surface, respectively; H is the observed value of the height of the isobaric surface; u and v are the observed values of the components of wind velocity along the X and Y axes; a_{ij} are the coefficients of the approximating polynomial; x and y are the dimensionless coordinates of the stations whose observations are used for the calculation; $x^2 + y^2 \leq R^2$; g is the acceleration of gravity; l is the Coriolis parameter; $p = \dfrac{1}{1+\alpha r^4}$, where $r = \sqrt{x^2 + y^2}$ is the distance from the station to the grid point, and α is a coefficient selected empirically; q is a weight factor characterizing the weight of wind data in the analysis of the geopotential-height field.

Thus, the solution of the overdetermined system of original (conditional) equations containing random observational errors is equivalent to solving the system of principal (normal) equations

$$\frac{\partial S}{\partial a_{ij}} = 0 \quad (0 \leq i + j \leq 3), \tag{2}$$

whose order is equal to the number of unknown coefficients a_{ij}.

According to the computational scheme that was developed, objective analysis is carried out for 480 nodes of a rectangular grid (20 rows of 24 points in each row; grid interval $s = 250$ km), permanently fixed on the map sheet MPK-1 at a scale of 1 : 10,000,000. The grid of points for which the objective analysis is performed, and the standard network of temperature and wind sounding stations whose observational data are used for this purpose, are shown in Fig. 1.

Fig. 1

The objective-analysis scheme was implemented on the "Strela" electronic computer of the Computing Center of the Academy of Sciences of the USSR. The program for solving the problem consists of two parts.

The first part of the program is auxiliary. It is intended for the initial processing of observational data and for bringing them into a form convenient for carrying out the main calculations. The initial information is entered into the machine in the form in which it was received in the telegram. The data for each station occupy two memory cells. One of them contains the station index $IIiii$, and the other contains the height of the isobaric surface hhh in meters (without thousands), the wind direction dd in tens of degrees, and the wind speed ff in meters per second. Auxiliary information K is also entered into the machine; for all stations arranged in a definite order, it contains information on their coordinates and the values of a certain special constant characterizing the orientation of the grid points relative to the geographic coordinate system and intended for computing the components of the wind velocity along the axes of the selected rectangular coordinate system. With the aid of this auxiliary information, the station indices in the initial information are replaced by coordinates, and the stations of this array are arranged in a definite order for the purpose of finding them more rapidly during operation of the main program. Specifically, the entire region is divided into strips parallel to the Y axis, the width

which is equal to the grid spacing. Within each band the stations are renumbered in increasing order of ordinates. The auxiliary program occupies 120 memory cells and runs for 2 min.

When the main objective-analysis program is operating, in addition to the transformed field of initial information I, an auxiliary field of grid nodes U, renumbered row by row, is entered into the fast memory of the machine. Each memory cell corresponding to a given node contains its coordinates and the address of the next node to be computed. Thanks to this, any sequence for computing the nodes can be specified in advance, ensuring that the analysis is carried out first for those nodes in whose vicinity there is a denser network of sounding stations. The objective analysis of grid nodes not provided with sufficient initial information is carried out using data at computed nodes. The results of the objective analysis are also stored in the field U; the computed values of geopotential heights are sent to the corresponding cells of the field where the coordinates of these nodes were stored. Into the cells that "frame" the nodes twice (see Fig. 1), a sign indicating the absence of information is entered, which makes it very simple to select data from the computed nodes. Together with these cells, the field U occupies $28 \times 24 = 672$ memory cells of the machine.

The operation of the main objective-analysis program reduces to the performance of the following logical and arithmetic operations: 1) selection of data from the stations surrounding the node being computed; 2) computation of the weight multiplier p; 3) selection of data from computed nodes; 4) construction of the matrix of the system of normal equations; 5) solution of the system of normal equations; 6) organization of the program' s operation for computing the next node.

In the computation, observed data on geopotential heights and wind at sounding stations located at a distance of about three grid cells (750 km) from the node are used. In Fig. 1, for one of the nodes, the area whose observational data are used for the computation is shown by a solid line. Owing to the fact that the field of initial information I is ordered in a definite way, only those stations that are within the nearest six bands (Fig. 1) are tested for belonging to the neighborhood of the node being computed. To construct the system of normal equations, computed data are also used at the nearest 24 nodes for which the analysis has already been performed. In Fig. 1, the nodes whose interpolated geopotential data are used in carrying out the analysis at the central node

Figure 2

Figure 2: Figure 2

Figure 3

Figure 3: Figure 3

are indicated by a dashed line. To solve the system of normal equations, a self-restoring program occupying 90 memory cells is used. The main objective-analysis program occupies 324 memory cells of the machine. The analysis of one node, using data on geopotential heights and wind with selection of these data within a radius of 750 km, lasts about 10 sec.

The scheme was tested on examples of the analysis of maps AT_{850}, AT_{700}, AT_{500}, and $OT_{500/1000}$. The examples were computed in several variants for different values of α ($\alpha = 0.01$; 0.03; 0.04) and for different sizes of the area radius when selecting data from stations (750 and 500 km), depending on the coverage of the territory by data. The results of the machine analysis of maps of all levels proved to be very good. The discrepancy between the results of the machine and subjective analysis of the geopotential-height field is on average less than 1 decameter. As an example, Fig. 2 shows the isohypses of the AT_{700} map for 03 hours on 24 February 1959, drawn by a synoptician in the usual way from observational data at sounding stations. In Fig. 3 the isohypses of the same map are drawn from objective-analysis data at the grid nodes.

For this case, the mean (over 480 grid nodes) deviation of the machine-analysis data from the subjective analysis is 0.8 dkm, and the root-mean-square deviation is 1.1 dkm.

In addition to the geopotential-height field, objective analysis is also carried out for the fields of temperature, dew point, and wind at different levels of the atmosphere.

The results of the calculation of examples showed that the indicated scheme of objective analysis, implemented on an electronic computer

Fig. 2

Fig. 3

of high speed—for example, on the M-20 machine—and supplemented by a subprogram for rejecting data with large errors, may be recommended for operational work.

Examples of numerical forecasts based on the use of objective-analysis data will be given in another article.

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CITED LITERATURE

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Note: Figure translations are in progress. See original paper for figures.