Validation of the output of the global atmospheric model on days with the development of dangerous convective phenomena according to aerological sounding with a two-day lead time

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Abstract. Data from aerological sounding of weather stations in the North Caucasus (Mineralnye Vody, Divnoye), in days with the development of dangerous convective phenomena, were used to validate predictive data (with two-day advance) of the global atmosphere model GFS NCEP. A high degree of overlap between predicted and actual data is shown based on correlation analysis.

1. Introduction
In recent years, there has been a tendency in our country to significantly reduce both the points of aerological radio sounding of the atmosphere and their frequency. This situation had an especially adverse effect on the quality of forecasts of hazardous weather phenomena associated with convection in the atmosphere.

Dangerous weather phenomena such as a thunderstorm, hail, barrage, etc., are caused by zones of active convection and belong to mesoscale meteorological processes. They are formed as a result of the complex interaction of atmospheric processes of macro, meso and micro scale.

The characteristic values of these phenomena are usually less than the distance between the points of meteorological and, especially, aerological observations in the modern observation network. All this makes it more difficult to conduct research using mathematical modeling of clouds and to predict dangerous weather events associated with zones of active convection. All this determines additional difficulties in conducting research using mathematical modeling of clouds and in predicting dangerous weather phenomena associated with zones of active convection.

A sufficient coincidence of the predicted values of atmospheric stratification obtained from global atmospheric models with the actual data of upper-air sounding would mean solving the important problem of the lack of baseline data on a large territory of our country, with the necessary resolution and lead time, for weather forecast calculations.

In this paper, the degree of coincidence of the predicted values of atmospheric stratification with a lead time of 48 hours obtained from the global atmospheric model with the actual data of aerological sounding conducted in the North Caucasus region at the Mineralnye Vody weather station is investigated. The study is conducted in order to identify the dynamics of changes in the quality of forecasting hazardous events with an increase in their lead time.
2. Materials and research methods
The first models of numerical weather prediction appeared almost simultaneously with the advent of the first computers. These were very imperfect models based on one two-dimensional equation of atmospheric vortex transport. With the development of computer technology, the models of operational weather forecasting gradually became more complex: in the mid-sixties of the 20th century, one two-dimensional equation gave way to a system of shallow water equations on a sphere. Towards the end of the sixties, computational methods were developed to solve three-dimensional equations of the atmosphere [6]. In return, the increase productivity of computers in the early seventies led to atmospheric models based on a complete three-dimensional system of atmospheric equations. After that, the development of atmospheric models went along with an increase in resolution, in the direction of increasing complexity of the parametric description of subgrid-scale processes (for example, outgoing and incoming radiation, precipitation, free flow interaction with the relief).

This paper uses the output data from the Global Atmosphere Model [9]. In the latest version of this model, the calculations are performed on a Gaussian grid with a resolution of (768x384), which approximately corresponds to the horizontal resolution of 0.5° latitude-longitude grid. Vertically, the atmosphere (from the surface of the earth to the height of the isobaric surface of 0.27 hPa) is divided into 64 layers. The relief of the Caucasus region according to this model with a mark (*) of the sounding point is shown in figure 1.

![Digital model of the relief of the Caucasus with a mark (*) of the sounding point. Isohypses - in meters.](image)

Global model of high spatial resolution atmosphere (T254) has a 3-hour time resolution of 0-180 hours for the forecast and 12 hours of 180-384 hours for the forecast. The calculation time for the lead time of one day is 12 minutes. Output products are issued on-line at the initial dates of 0, 6, 12, 18 hours UTC (Coordinated Universal Time) and updated every 6 hours.

The model output in the form of a radiosonde used in methods for predicting convective processes is shown in figure 2.
This figure shows the prognostic fields on isobaric surfaces from 1000 to 100 mb of such meteorological elements as:
- air temperature (t, °C);
- dew point temperature (t, °C);
- wind speed (W, m/s);
- wind speed directions (°, degrees).

Actual values of the same fields on the above indicated isobaric surfaces can be obtained by aerological sounding of the atmosphere, carried out in Mineralnye Vody.

Note that this set of meteorological elements is the basis for calculating the parameters of the atmosphere and convective clouds, which are widely used in prediction methods for both convective clouds and the phenomena associated with them [1, 8, 4, 3, 5]. In addition, when modeling three-dimensional convective clouds, it becomes possible to set the initial data in bulk [2].

A quantitative assessment of the proximity of predicted and actual values of air temperature and dew point, wind speed and direction at various isobaric levels is carried out by correlation analysis methods.

3. Research results and discussion
As a result of research, two data sets were generated for the following meteorological parameters: air temperature, dew point temperature and wind speed at various isobaric levels. The first (predictive) data set was obtained according to the Global Atmosphere Model 48 hours before the aerological sounding. The second data set (actual) was created based on the results of upper-air sounding, after two days (usually at 16 hours).

The proximity of these data sets was quantified using the SPSS software. Correlation coefficients with corresponding significance levels are calculated. In the table 1 the correlation between the actual (Tzem, T700, T400) and predictive (TPzem, TP700, TP400) air temperatures at isobaric levels of zem, 700 mb and 400 mb, respectively, with a lead time of 48 hours is shown. The isobaric zem level corresponds to the level at the ground, approximately 1000 mb.
### Table 1. Correlation between actual and predictive values of air temperature.

| Characteristics       | Tzem | TPzem | T700 | TP700 | T400 | TP400 |
|-----------------------|------|-------|------|-------|------|-------|
| Pearson Correlation   | 1    | 0.91* | 1    | 0.97* | 1    | 0.97* |
| Relevance (2 sides)   | 0.00 | 0.00  | 0.00 | 0.00  | 0.00 | 0.00  |
| Sum of squares and    | 5855 | 4472  | 2615 | 2562  | 3023 | 3255  |
| paired products       |      |       |      |       |      |       |
| Covariance            | 84.85| 64.81 | 39.04| 38.24 | 45.12| 48.58 |
| Number of observations| 70   | 70    | 68   | 68    | 68   | 68    |
| Pearson Correlation   | 0.91*| 1     | 0.97*| 1     | 0.97*| 1     |
| Relevance (2 sides)   | 0.00 | 0.00  | 0.00 | 0.00  | 0.00 | 0.00  |
| Sum of squares and    | 4472 | 4120  | 2562 | 2653  | 3255 | 3690  |
| paired products       |      |       |      |       |      |       |
| Covariance            | 64.81| 59.72 | 38.24| 39.60 | 48.59| 55.08 |
| Number of observations| 70   | 70    | 68   | 68    | 68   | 68    |

* Correlation is significant at the level of 0.01 (2-sided)

Visualization of air temperature values for both data sets (predicted and actual) at isobaric levels zem, 700 mb and 400 mb is presented in figure 3.

![Figure 3](image-url)

**Figure 3.** Air temperature at various isobaric levels zem, 700 mb and 400 mb solid lines – actual data, dashed lines – predicted data with a lead time of 48 hours.

Figure 3 also shows that the actual (solid lines) and predicted (dashed lines) air temperatures at various levels are very close.
Similar research was conducted for dew point temperature, wind speed and direction at various isobaric levels. The data of the correlation analysis for these atmospheric parameters are given in Table 2.

| Isobaric levels, mb | Air temperature | Dew point temperature | Direction of the wind | Wind speed |
|---------------------|-----------------|-----------------------|-----------------------|-----------|
| 1000 (zem)          | 0.91            | 0.92                  | 0.95                  | 0.88      |
| 900                 | 0.94            | 0.88                  | 0.85                  | 0.83      |
| 850                 | 0.97            | 0.96                  | 0.81                  | 0.90      |
| 800                 | 0.95            | 0.90                  | 0.94                  | 0.89      |
| 700                 | 0.98            | 0.88                  | 0.88                  | 0.91      |
| 600                 | 0.95            | 0.81                  | 0.93                  | 0.92      |
| 500                 | 0.98            | 0.80                  | 0.89                  | 0.96      |
| 400                 | 0.95            | 0.81                  | 0.69                  | 0.94      |
| 300                 | 0.89            | 0.77                  | 0.94                  | 0.95      |

* Correlation is significant at the level of 0.01 (2-sided)

Table 2 shows that all atmospheric parameters have high and very high correlation coefficients. Even such a variable and difficult to predict, but at the same time important parameter, like the dew point temperature (humidity) at the earth's surface, has a correlation coefficient (0.92) with actual humidity.

Previously, the output of the global model was validated with a lead time of 24 hours on the results of upper-air sounding [7], according to which high correlation coefficients were also obtained. The consecutive increase in the lead time of the weather forecast up to 48 hours, studied in this work, did not lead to a noticeable decrease in the correlation coefficients. This fact allows us to consider in the future forecasts for medium terms (3-5 days).

4. Conclusion
The results obtained indicate the high quality of the output products of the global GFS NCEP model. Predicted values of atmospheric stratification can be used in operational units to make forecasts of hazardous phenomena and weather elements (replacing actual aerological sounding) which is not yet predictable by the global atmospheric models themselves.

The high degree of coincidence of the model data with the data of aerological sounding also suggests that their use as input in the calculation of powerful convective clouds, based on their three-dimensional models, can be quite fruitful. In this case, the initial conditions can be formed at the grid nodes of the three-dimensional region in which the cloud will be calculated. It must be emphasized that a good coincidence between the values of atmospheric parameters according to the GFS model with the actual data was obtained despite the lead time of 48 hours. This means that when they are used as initial data in the calculation of the three-dimensional cloud model, there will be a noticeable margin of time, so necessary for updating the calculation results for operational use.

Thus, it is shown that the use of the output of modern global models to solve a wide range of meteorological problems is quite justified and has good prospects.

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