NUMERICAL INVESTIGATION OF THE CAUCASIAN REGION RELIEF INFLUENCE ON DISTRIBUTION OF HYDROMETEOROLOGICAL FIELDS

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Abstract: By numerical integration of the non-adiabatic, non-stationary and non-linear equations of an atmosphere hydrothermodynamics the influence of the Caucasian Region relief on a space distribution of meteorological fields is investigated. The dimensionless vertical coordinate, which in numerical experiments enables approximate the real relief with high accuracy, is used. The air motions over the Caucasian Region in presence of large-scale background western, eastern, northern and southern winds are simulated. It is shown that action of the relief on the basic four types of large-scale movements can cause an essential change of the background hydrometeorological fields in the lower troposphere and forms mesoscale structures of the wind, temperature, pressure and moisture fields.

Keywords: *Caucasian Region, numerical modeling, background winds, influence of relief, hydrometeorological fields, diurnal oscillation of temperature*.

1. INTRODUCTION

The Caucasian Region has very complex relief, which is limited from the west and the east by the Black, Azov and Caspian seas (Fig. 1). In the central part of this region the high mountain ridges – the Main Caucasian Ridge, Minor Caucasian Ridge and Ponto Ridge are located. They are separated by hills, flats and low territories. A landscape of the Caucasian is also rather various. Such variety of an underlying surface creates the certain difficulties for numerical modeling of atmospheric processes evolution. The regional atmospheric models (Khvedelidze, 1996; Mikashavidze, 1998) in consequence of some simplifications and insufficient spatial resolution, do not allow taking into account the local features of the Caucasian Region relief and adequately describe the structure of the hydrometeorological fields.

2. MODEL DESCRIPTION

The numerical model elaborated in M. Nodia Institute of Geophysics is used for investigation of atmospheric processes developed in the Caucasian Region. The model uses the coordinate system (Gutman, 1969) $x,\ y,\ \zeta = \dfrac{z - \delta(x,\ y)}{H(t,\ x,\ y) - \delta(x,\ y)}$. Here x, y and z are the Cartesian coordinates and are directed to east, north and vertically upward, respectively; ζ is non-dimensional vertical coordinate; $\delta = \delta_0(x,\ y) + 100\text{m}$; δ_0 and H are heights of the relief and tropopause, respectively. Using of non-dimensional ζ coordinate allows us to take into account the relief in the numerical model with high accuracy.

The rectangular area with horizontal sizes $1500\,\text{km} \times 1200\,\text{km}$ along the parallel and meridian is considered. It includes the Caucasian, east part of the Black and Azov seas and the western part of the Caspian Sea. The troposphere, active layers of soil and seas are considered in this area. The troposphere from below is limited by surface layer of air and from above – by changing in time and space tropopause tropopause. Evolution of the meteorological fields in the atmosphere is described by full system of hydro-thermodynamic equations of the atmosphere (Marchuk, 1974; Pernenko, 1981; Kordzadze et al., 1998). The mathematical model takes into account the non-adiabatic processes of condensation, evaporation and precipitation, the processes of horizontal and vertical turbulence exchange of the heat and momentum (Marchuk, 1982; Matveev, 1984; Marchuk at al., 1984; Belov at al., 1984). In the active layer of the soil the heat and moisture transfer equations are used (Chudnovskij, 1976), and in the active layer of the sea – the heat transfer equation (Matveev, 1984). On the interface levels of the soil-atmosphere and sea water-atmosphere for the boundary conditions the heat balance equation is used (Marchuk, 1982; Matveev, 1984).

In the model the standard boundary conditions and parameterization formulas for non adiabatic processes of condensation and evaporation, vertical turbulence transfer of heat and momentum are used (Marchuk et al., 1984; Belov et al., 1984).

For numerical integration of the model equations Shuman's numerical scheme (Shuman et al., 1968) for the atmosphere and the Krank-Nikolsons scheme for soil and sea water are used. The rectangle numerical grid with $26 \times 24 \times 17$ points is used. The horizontal steps are equal to 50 km and the vertical step is equal to 1/17. In the soil and sea basin the amount of the grid levels is equal to 20 with steps equal to 5 cm. The time step is equal to 1 min. The numerical integration was continued more than 10 days.

The background values of the temperature and pressure fields were chosen so, were modeled the Caucasian relief flow by the west, east, north and south background winds. The values of background wind speeds were determined by the formulas of the geotropic wind and were growth from 2m/s on the level z = 100 m to 25.3 m/s on the tropopause. The background value of the relative humidity of the atmosphere was equal to 40%, the background values of cloud water was equal to 0.

3. RESULTS

In Fig. 2 the space distribution of wind field on the level z=1 km in case of flow the Black Sea region by background western wind, obtained at the moment t = 12 p.m., is shown. From this figure it is visible that the surrounding of the Black Sea relief causes considerable change of the space distribution of the background wind field not only over the high mountain ridges, but also surrounding seashore zones and lowland territories. The Main Caucasian, Minor Caucasian and Phonto ridges are resistance with three side of air motion to east and this promotes accumulation of air near the east part of Black Sea and causes growth of ground-level pressure. As a result the direction of the west wind is changed and wind consistently becomes as the south-western, western and south-eastern winds. In the central and east parts of the Caucasian Region the shape of relief and orientation of ridges forces air to spread along the lowland territory among the mountain ridges. Here, as a result, the north-west and south-west winds are formed. As a whole influence of the relief on the background western wind causes formation of the anticyclone wind vortex.

Figure1: Relief of the Caucasian Region

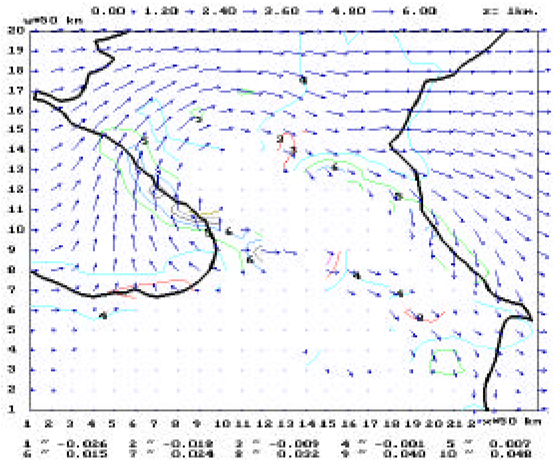

Figure 2: Distribution of the wind velocity vectors (m/s) and izolines of the vertical velocity (cm/s) in case of backdround weastern wind at t = 12 p.m.

The kinematical picture of influence of the Caucasian Region relief on the background eastern wind is significantly different. In this case the wind is "soaked up" between Main Caucasian and Minor Caucasian ridges along the lowland and flat territories. In case of flow region relief by northern background wind the air stream is divided into the western and east streams. The western air flow streamlining the Main Caucasian Ridge from western side meets on his way the resistance of the Ponto Ridge and forms the cyclonic wind vortex on the eastern side of the Black Sea. The eastern air flow forms the anticyclonic wind vortex in the vicinity of the western shores of the Caspian Sea. In case of the Caucasian Region relief flow by southern background wind the cyclonic and anticyclonic vortexes of the wind in the eastern and western parts of the Caucasian Region and a “return flow” of air in the leeside of the Main Caucasian Ridgem, are obtained.

The space distribution of the vertical speed of the wind in the low troposphere is complex. In general, in vicinities of the windward and lee sides of the ridges (relatively the background wind) the zones of descending and ascending movements of air are received. The local distribution of these zones depends from structure of formed mesoscale circulating systems. In the middle troposphere the space distribution of the vertical velocity is little other than in the lower troposphere. As a hole in the region of the windward side the ascending movements of air and in the region of the lee side – the descending movements are obtained. Quantitatively vertical velocity has the maximal values in vicinities of greater heights of the Main Caucasian ridge. The values of the vertical velocities changes in the interval from -10 cm/s up to 15 cm/s.

The diurnal oscillation of the air temperature essentially depends from situation of the point in the region (Fig. 3). Above the seas the amplitude of the diurnal oscillation of temperature on the level 100m does not exceed 1-2^{0}C, but above the earth ground it reaches to 4^{0}C. The amplitude of the diurnal oscillation of the sea water temperature is equal to 0.05-0.07^{0}C, but that on the surface of soil are into interval 25-30^{0}C. By the depth in the soil the amplitude of the diurnal oscillation of temperature gradually decreases and on the level 1m not exceed 0.1^{0}C.

Air flow of the Caucasian Region relief is accompanied by evaporation water from the sea surface, vertical and horizontal motion of water vapor, condensation of water vapor in the areas of intensive ascending movement and formation of the crest clouds. The clouds formation process begins approximately in 1 hour after beginning of air flow modeling process, letter 2 hours begins precipitation and still 4 hours later some well development rain cloud systems are obtained (Fig. 4). In the vicinity of the high mountains both anabatic clouds and lee wave clouds are obtained. Over the most parts of cloud formation territory (except the places with intensive ascending movements of air) the clouds arise and disappear with periodicity about 5-7 hours.

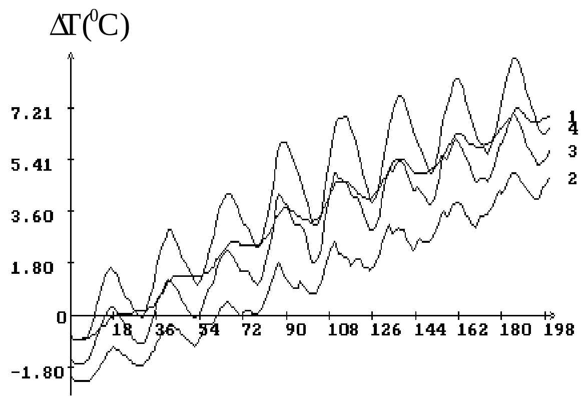

Figure 3. Diurnal oscillation of the air temperature amplitude $\Delta T(^0C)$ above the sea point (curve 1) and three points of the soil (curves 2-4) on the level z=100m.

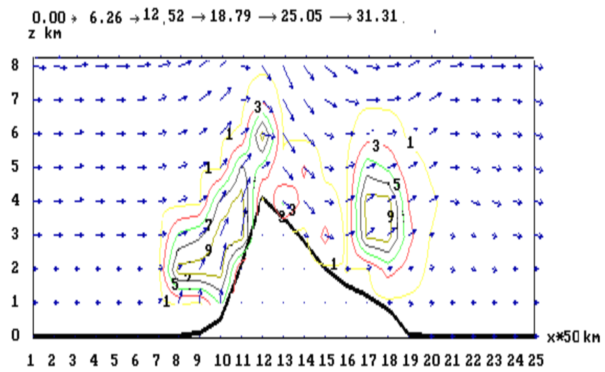

Figure 4. Distribution of the wind velocity (m/s) and the atmospheric water (10^{-1}g/kg) in the latitudinal section X0Z ($y = 13 \times 50$km)at the moment t=4 p.m.

Analyze of spatial distribution of obtained pressure field shows that interaction of the relief and background winds forms the meso-scale zones of increase and decrease of the surface pressure with amplitudes approximately equal to 5-15 Mb. These zones have different spatial extent and shape. The zones of increase and decrease of the surface pressure are mainly located with windward and lee side of basic mountains ridges, respectively.

4. CONCLUSION

As it is apparent the spatial and temporal distributions of meteorological fields (pressure, temperature, wind speed, clouds, etc.) obtained by this model, are well agreed with data known from observations (Papinashvili, 1963; Handbook ..., Wind, 1968; Handbook ..., Temperature ..., 1968; Climate ..., 1971, Textbook ..., 1986). The model more realistic and detail describes evolution of atmospheric processes in the Caucasian Region than other regional models which are used in the practical and scientific purposes.

In additional, the results obtained by modeling supplements our knowledge of understanding of the mechanism of development atmospheric processes in the Caucasian region with new theoretical representations.

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Khvedelidze Z., Khvedelidze R. On the influence of the relief on the geopotential in the lover layers of the atmosphere. *J. Georgian Geophys. Soc*., 1996, volume **1**, 51-58.

Mikashavidze B. Some features of a relief influence account in problems of weather forecast. *Proceed. of institute of Hydrometeorology*, 1998, volume **101**, 38-45 (in russian).

Gutman L. N. Introduction in the nonlinear theory of mesometeorological processes in atmosphere. L.: Gidrometeoizdat, 1969, 296 pp. (in russian).

Marchuk G. I. Numerical solution of atmosphere and ocean dynamics problems. L.: Gidrometeoizdat, 1974, 304 pp. (in russian).

Penenko V. V. Methods of numerical modelling of atmospheric processes. L.: Gidrometeoizdat, 1981, 252 pp. (in russian).

Marcuk G. I. Mathematichal modelling in problem of environment. M: Naukae, 1982, 320, (in russian).

Kordzadze A., Surmava A. Mathematical model of middle-scale movements over the Caucasian region in free atmosphere. *J. Georgian Geophys. Soc*., 1998, volume **3B**, 66-73.

Matveev L. Rate of the general meteorology. Physics of atmosphere and ocean. L.: Gidrometeoizdat, 198 4, 752 pp. (in russian).

Chudnovskij A. F. Physics of heat of soils. Ì.: Nauka, 1976, 352 pp. (in russian).

Marchuk G. I., Dimnikov V. P., Zalesni V. B., Likosov V. N., Galin V. J. Mathematical modelling of general circulation of atmosphere and ocean. L.: Gidrometeoizdat, 1984, 320 pp. (in russian).

Belov P. N., Borisenkov E. P., Panin B D. Numerical methods of weather forecast. L.: Gidrometeoizdat, 1989, 376, (in russian).

Shuman F. G., Hovermale L. R. An operational six-layer primitive equation model. *J. Appl. Mech*., 1968**, 7**, 4, 525-547.

Papinashvili K.I. Atmosfernye processes in Transcaucasia and their connection with macrocirculating processes above Eurasia. L.: Gidrometeoizdat, 1963, 184 pp. (in russian).

Hand-book on climate of the USSR. Wind. L.: Gidrometeoizdat, 1968, issue 14, p. 2, 388 pp. (in russian).

Handbook on climate of the USSR. Temperature of air and ground. L.: Gidrometeoizdat, 1968, 14, p.3, 375 pp. (in russian).

Climate and climatic resources of Georgia. Edit. Lominadze V. P., L.: Gidrometeoizdat, 1971, 384 pp. (in russian).

Textbook on short-term weather forecast. L.: Gidrometeoizdat, 1986, 703 pp. (in russian).