Influence of meteorological situation on infrasound propagation

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In this paper, we analyze the change in the azimuth of arrival of microbaroms – infrasound signals from storm formations in the North Atlantic and the Pacific, recorded on weather charts. The relation between the microbarom azimuth and the position of the source is analyzed along with the relations between the main characteristics of microbaroms and the positions of cyclones in the propagation path and at the observation site. Experimental data are compared with the infrasound propagation path model constructed on the basis of the modern MSISE-2000 model of the atmosphere.

Introduction

The long-distance propagation of infrasound signals from storm regions of seas and oceans (microbaroms) is determined by the structure of the Earth's atmosphere. The altitude temperature distribution and wind direction are such that there arise atmospheric acoustic channels in the atmosphere. Spatial extension of the channels can reach few thousand kilometers. Altitudes corresponding to the long-distance propagation (H = 15–20 and 60–80 km) relate to the 1st and 2nd temperature minima, respectively. Today we have not a clear notion of how the atmospheric channels catch and extract the acoustic energy. Therefore, a general problem is to study the conditions for forming and functioning of the atmospheric acoustic channels through the natural acoustic radiation of seas and oceans (microbaroms) using the present day models of the atmosphere and aerologic atmospheric sounding data (altitude profile of the wind velocity and direction). In this paper, we consider the influence of meteorological situations on the long-distance propagation and reception of infrasound signals from storm formations – microbaroms, and compare the observations with experimental data obtained on the basis of the MSISE-2000 model of the atmosphere.[1,2]

Characteristic of aerological data

Aerological atmospheric sounding data were obtained from the everyday launching of meteorological balloons. The launching were carried out by the Irkutsk Office of the Hydrometeorological Service in 1986. The following data were measured (all up to 30 km): altitude temperature profile, wind velocity, and wind direction.

The current status of the problem

Great interest in infrasonic waves has been expressed in the USA in 1960–1970s. As a result of 10-year registration of microbaroms (Paliseid st., Empire State) from storm regions in the Atlantic and using data of other measurements, W. Donn and D. Rind received the time percent of microbaroms reflection at different altitudes, characterizing a prolonged existence of strong east tidal winds responsible for the acoustic channel.

Permanent regular observations of microbaroms arriving from the North Atlantic and the Pacific northwest were carried out from 1976 to 1993 at the Infrasound station Badary. The lifetime of acoustic channels was estimated for Atlantic and Pacific origins.[3]

By now, the International monitoring system is organized in the context of the Comprehensive Nuclear Test-Ban Treaty (CTBT), which includes 60 infrasound stations, a dense network of ground meteorological stations, as well as satellite atmospheric sounding data.

Data and methods in use

To estimate conditions for the long-distance infrasound propagation, it is necessary to know the structure of the atmospheric waveguide channel, i.e., the temperature and wind velocity profiles for the altitudes from 15 to 45 km. For this purpose, the standard Meteorological Service data of aerological atmospheric sounding at 1 km off-duty ratio are used.

Alternatively, modern global models of the atmosphere, for example MSISE-2000 (Ref. 2), provide for obtaining such profiles over every point of the Earth at every instant. The input parameters for the model are the date, time, coordinates of the site under study, and indices of solar and magnetic activity.

Without loss of generality the atmosphere may be considered as a horizontally homogeneous medium for the wavelengths much less than dimensions of synoptic formations ($\lambda \ll 100–500$ km). The gravity and the curvature of the Earth surface can be neglected for the wavelengths much less than vertical atmospheric inhomogeneity (the height of the homogeneous atmosphere). Thus, the velocity of particle displacement

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in a wave for the harmonic frequency ω can be written as

$$u = A(z)\exp(-ik_x x), \quad (1)$$

where k_x is the horizontal component of the wave vector, z-axis is directed upward. At $\lambda < H = c^2/\gamma g$, where $c^2 = \gamma P_{0g}/\rho_0$ (index 0 corresponds to zero level of the atmosphere, i.e., the sea level, γ is adiabatic exponent, g is acceleration of gravity, P_0 is atmospheric pressure, ρ is density), the sound propagation is described by the equation

$$u'' + Uu = 0, \quad (2)$$

where

$$U = \Omega^2/c^2 - k_x^2$$

is some function of the sound velocity (temperature) and of horizontal wind velocity V, since

$$\Omega = \omega - k_x V.$$

Further the function U is arbitrarily called the potential.[4] All space of sound propagation is divided into two domains, namely, the waveguide propagation domain ($U > 0$) and the domain of free propagation of sound ($U < 0$). Thus, the analysis of the potential allows us to separate in space regions of sound channeling for preset values of ω and k_x. Obviously, the sound velocity is minimal along the waveguide axis $z = z_c$ and increases up and down from it.

The role of the horizontal wind is reduced to changing the wave frequency and the size of the horizontal projection of the wave vector. Therewith, ω changes to $(\omega - kV)$ and k_x changes to $k_x(1 + V/c)$. Thus, the fair wind decreases the frequency and increases the horizontal wave number. The signal is such as if it rested against the waveguide axis. Evidently, channeling conditions amend in this case. The head wind causes the reverse situation. It is interesting to note that such wind effect is observed in reality as well. According to Ref. 3, microbaroms come from North Atlantic storms under the west wind and from Pacific storms under the east wind. Hence, to clarify the spatial (first of all, altitude) distribution of sound and wind velocity is of great importance for understanding the possibility of long-distance propagation of signals.

Procedure of experimental data analysis

Experimental data on the azimuth of arrival of microbaroms was analyzed based on regular measurements at the Infrasound metrical station of ISTP SB RAS. As an example, January of 1986 is considered as the characteristic period of infrasound propagation under winter conditions and as a period of the highest storm activity on source. It should be noted that the data of other years have the same tendency. The results of the analysis are presented in Fig. 1.

Hours are laid on the horizontal axis; date, azimuth of infrasound signal arrival, and wind direction at the height of minimum of altitude temperature profile – on the vertical axis. Meteorological data (azimuth of wind direction) were also used in the analysis and treatment of angular distribution of arrival of infrasound signals. From the minimal value of temperature, we refined the position of the axis of an atmospheric acoustic channel, where horizontal wind direction and its correspondence to infrasound propagation direction were determined. The data on the azimuth of arrival of microbaroms and wind direction were separated into two gradations: 0–180° and 180–360°, i.e., west and east directions. Under these conditions, the receiving infrasound signals corresponding to the North Atlantic and Pacific Ocean, were selected.

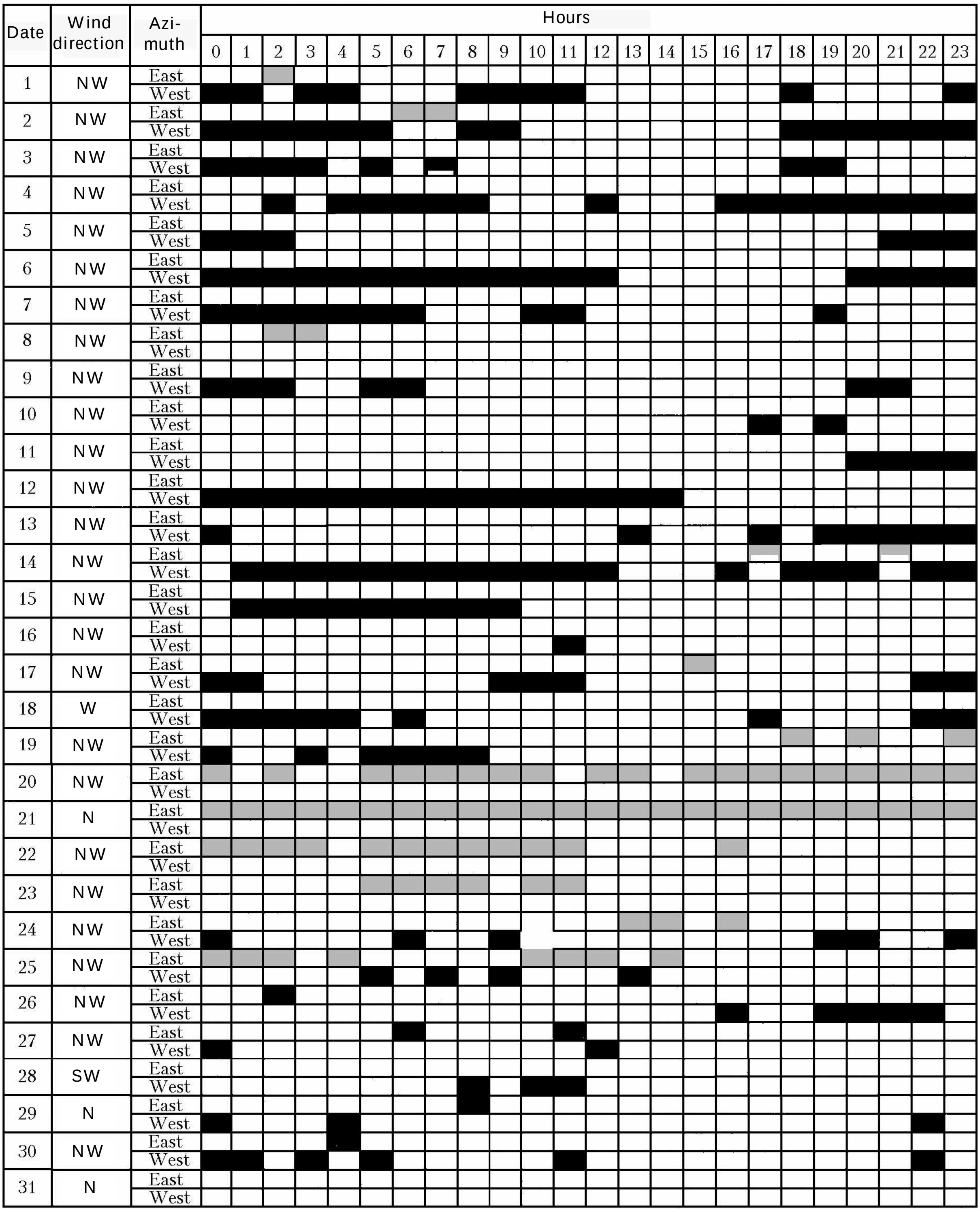
Preliminary results of the analysis of experimental data and their comparison with calculations

Azimuthal distribution of angles of arrival of microbaroms is shown in Fig. 1. It is seen that during the first 19 days of January, 1986 the microbaroms came from the west (the North Atlantic), and beginning from January 20, microbaroms generally came from the north-west of the Pacific Ocean. Actually, the storm activity in the North Atlantic in January of 1986 was very high according to synoptic data. An example of a synoptic condition in this region for January 12, 1986 is shown in Fig. 2, where the extensive cyclone of about 980 mbar in depth can be seen.

It follows from Fig. 1 that during more then a half (19 days) of January of 1986 microbaroms came with the azimuth of 180–360°, i.e. from northwest (from the North Atlantic), when the azimuth of arrival of infrasound signals coincided with the northwest wind direction at the minimum of temperature profile (at the atmospheric waveguide axis). When infrasound signals came from the east (from the Pacific), the azimuth of their arrival coincided with the wind direction fixed at the axis of the atmospheric acoustic channel. Hence, wind at a height of atmospheric waveguide has filtering properties and determines the capacity of the atmospheric acoustic channel.

The most active and representative days in the period under study are the 6th and 12th of January (arrival of infrasound from the North Atlantic) and the 21st and 22nd of January (arrival of infrasound from the Pacific).

These two directions of signal arrival correspond to the northwest and northeast wind directions, respectively. Consider, how the models describe the effective refraction index responsible for formation of the atmospheric acoustic channel, i.e., the parameter U, arbitrarily called the potential.



Date	Wind direction	Azimuth	Hours																							
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	NW	East			▒																					
		West	■	■		■	■				■	■	■	■							■					■
2	NW	East							▒	▒																
		West	■	■	■	■	■	■			■	■									■	■	■	■	■	■
3	NW	East																								
		West	■	■	■	■		■		■											■	■				
4	NW	East																								
		West			■		■	■	■	■	■				■				■	■	■	■	■	■	■	■
5	NW	East																								
		West	■	■	■																			■	■	■
6	NW	East																								
		West	■	■	■	■	■	■	■	■	■	■	■	■	■								■	■	■	■
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		West																								
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		West	■	■	■			■	■														■	■		
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		West																		■		■				
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		West																					■	■	■	■
12	NW	East																								
		West	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
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		West	■													■				■		■	■	■	■	■
14	NW	East																		▒				▒		
		West		■	■	■	■	■	■	■	■	■	■	■	■				■		■	■	■		■	■
15	NW	East																								
		West		■	■	■	■	■	■	■	■	■														
16	NW	East																								
		West												■												
17	NW	East																▒								
		West	■	■								■	■	■											■	■
18	W	East																								
		West	■	■	■	■	■		■											■					■	■
19	NW	East																			▒		▒			▒
		West	■			■		■	■	■	■															
20	NW	East	▒		▒			▒	▒	▒	▒	▒	▒		▒	▒		▒	▒	▒	▒	▒	▒	▒	▒	▒
		West																								
21	N	East	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
		West																								
22	NW	East	▒	▒	▒	▒		▒	▒	▒	▒	▒	▒	▒					▒							
		West																								
23	NW	East						▒	▒	▒	▒		▒	▒												
		West																								
24	NW	East														▒	▒		▒							
		West	■						■			■										■	■			■
25	NW	East	▒	▒	▒		▒						▒	▒	▒		▒									
		West						■		■		■				■										
26	NW	East			■																					
		West																	■			■	■	■	■	
27	NW	East							■					■												
		West	■												■											
28	SW	East																								
		West									■		■	■												
29	N	East									■															
		West	■				■																		■	
30	NW	East					■																			
		West	■	■		■		■						■											■	
31	N	East																								
		West																								

Fig. 1. The azimuths of arrival of microbaroms and wind direction. Badary station, January of 1986.

Figures 4 and 5 show the calculations of the altitude dependence of the effective refractive index of the acoustic channel U. It follows from the calculations that at altitudes up to 20 km, where $U > 0$, i.e., the wave vector is real the waveguide infrasound propagation takes place.

The waveguide is absent at altitudes from 25 km to 50 km, where $U < 0$ (wave vector is imaginary) and the free propagation of infrasound is observed. At altitudes about 100 km the parameter U is positive and points to the presence of the upper waveguide channel. However, taking into account that the long-distance propagation through that channel is accompanied by significant signal attenuation, we can consider it ineffective.

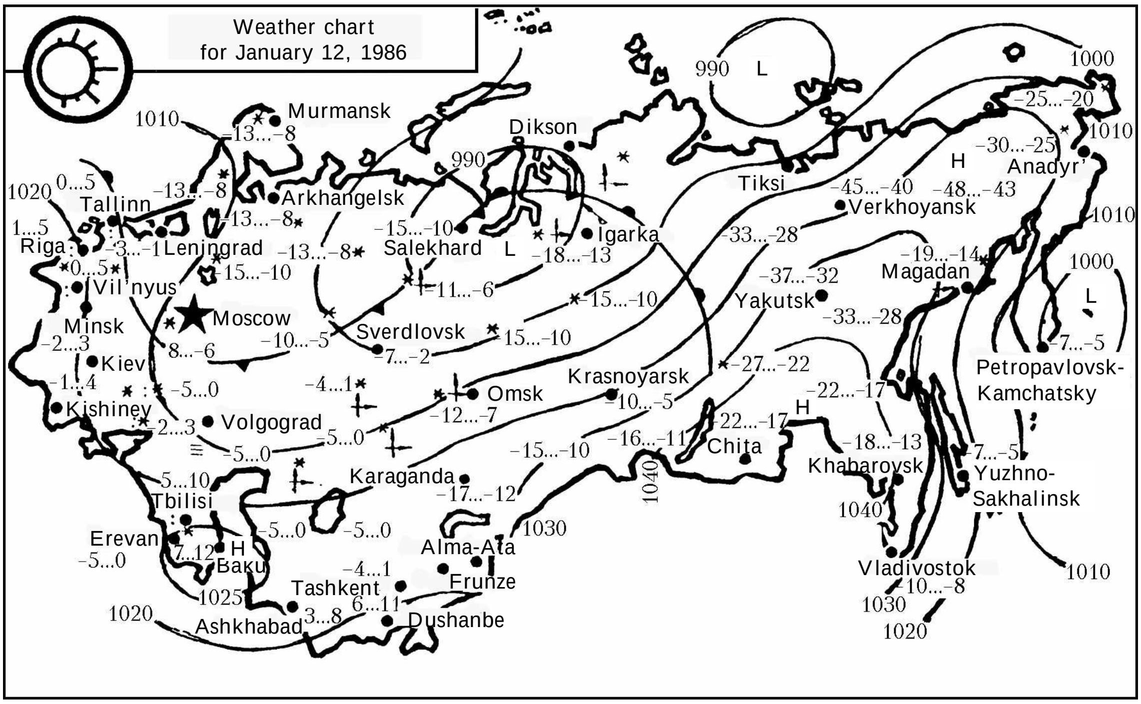


Fig. 2. Example of synoptic condition on 01.12.1986 (North Atlantic source).

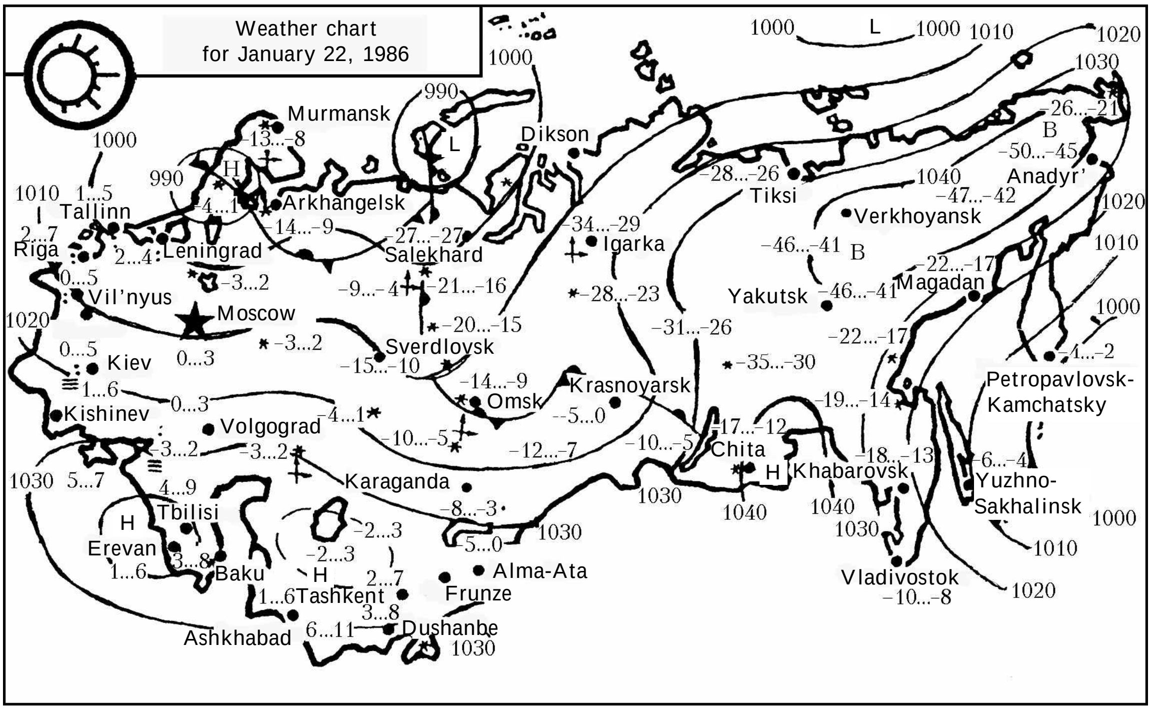
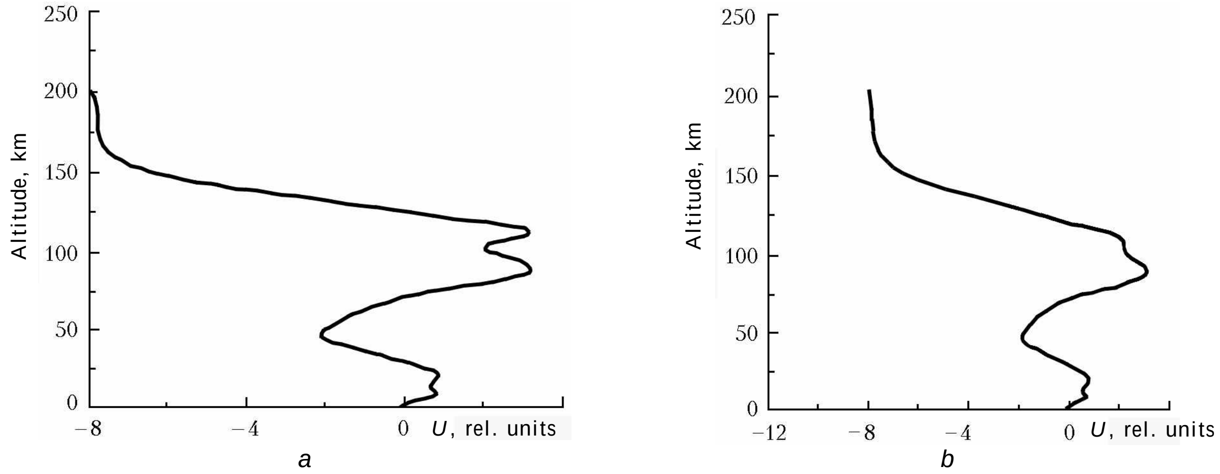


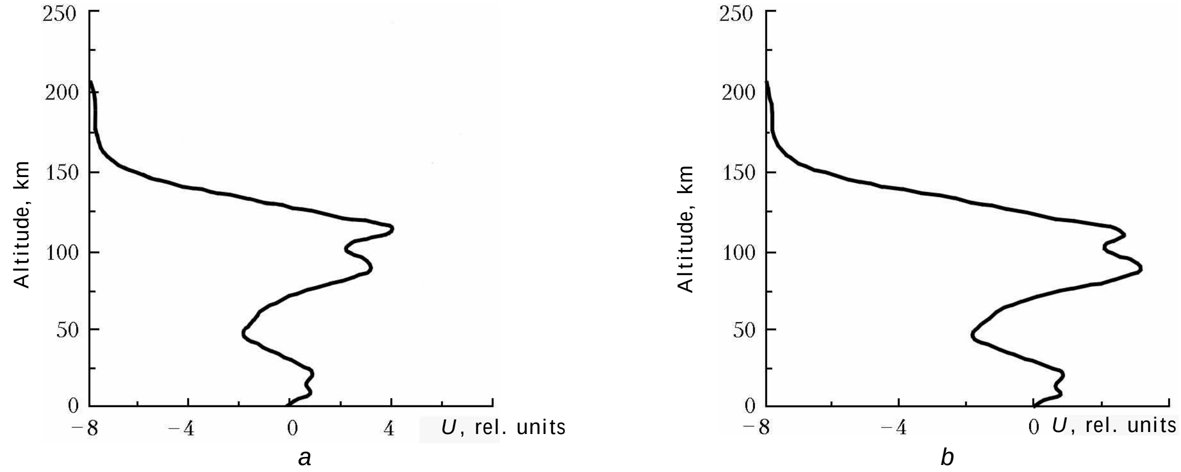
Fig. 3. Example of synoptic condition on 01.22.1986 (Pacific source).

The passage of microbaroms from North Atlantic to intracontinental Infrasound station Badary in Buryatia on the 6th and 12th of January of 1986 agrees with the classical concept of waveguide propagation of infrasound signals; the experimental data are in a satisfactory agreement with calculations. The calculations also show the presence of the atmospheric acoustic channel at altitudes of about 20 km for the 21st and 22nd of January (*U* > 0, Fig. 5), when the Pacific source operated (Fig. 3).



a *b*

Fig. 4. Efficient refractive index: January 6, 1986 (*à*); January 12, 1986 (*b*).



a *b*

Fig. 5. Efficient refractive index: January 21, 1986 (*à*); January 22, 1986 (*b*).

Acknowledgments

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