VLF sensors for lightning research

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The lightning localization task is very interested for the meteorologist organizations, airlines, networks operators, military and etc. The electromagnetic properties of lightning can be measured using VLF sensor. The paper deals with some VLF sensors hardware and software used in IKIR FEB RAS.

VLF sensor hardware

During the development of remote methods for investigation of magnetosphere dynamics, synoptic weather systems, detection of volcano explosive eruptions, we applied peculiarities of radio signal propagation. Radio pulses of lightning discharges (atmospherics). Radio pulses of lightning discharges, propagation along the Earth surface via the Earth-ionosphere waveguide, carry information on synoptic weather system structure, repeating by its intensity and spatial distribution the structure of cloud formations. The radio pulses, penetrating into magnetospheric waveguides, receive a characteristic form (whistler) and carry information on weather system state in the magnetosphere. Volcano explosive eruptions may also be accompanied by lightning discharges which may be applied to detect volcanic eruptions in the conditions of dense cloudiness. In general, the Very Low Frequency (VLF) sensor consists of a receiving part and a data acquisition module. The reception part consists of: antenna (see Fig. 1a), amplifiers, filters. Data acquisition module consists of: analog-todigital converter (ADC), digital recorder, time synchronization module, etc. As an integral component of the various types of VLF sensors considered the use of mini-computers, audio and video cards, specialized ADC, various types of antennas (Fig. 1b).

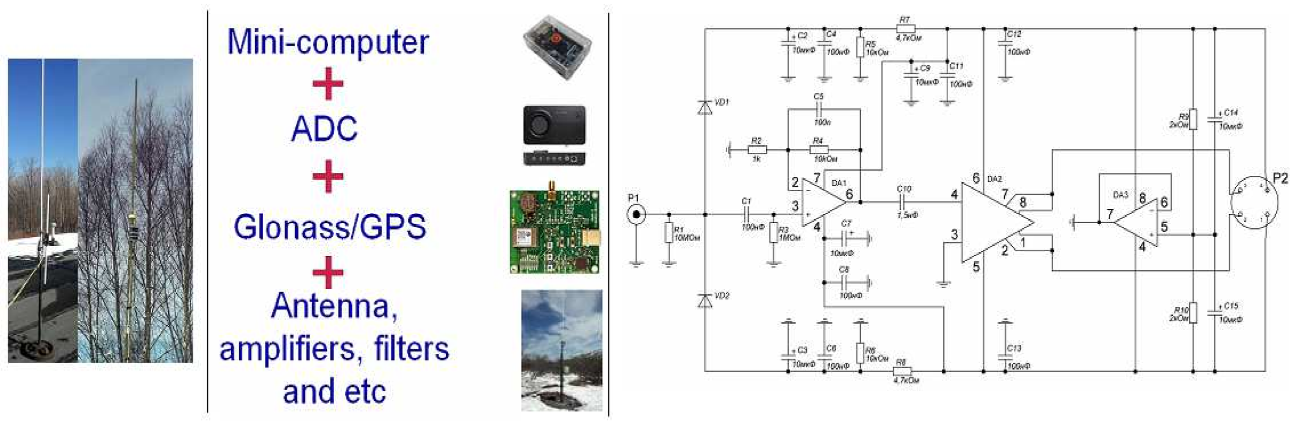


Fig. 1. (a) some types of antennas used in IKIR for whistler detection and lightning localization; (b) an example of VLF sensor components; (c) principle circuit of the preamplifier.

The preamplifier is fed from the AC adapter with the constant voltage from 25 to 30 V. The PA is in a metal casing and can be used outside all year round. The PA is installed in the immediate proximity to an antenna. For power supply and signal transmission from the PA, UTP5 cable (four screened twisted pairs) is laid outside. One pair in each arm is used for power supply, one twisted pair is used for signal transmission and one of them is not used. We mount the PA near the antenna, we may say that it is a part of antenna construction. An example of a prepared PA mounted on the antenna is shown in Fig. 2b. After installation, the PA does not require adjustment and is ready to be operated if properly mounted. As long as antennas are not standardized device, the level of the signal on each of them will be different. The gain of the first cascade may be altered by changing the nominal of R2 and R4 resistors within some limits. There are no strict requirements to the level of output signal. It is important that the level of «powerful» atmospherics does not exceed the maximum input voltage of the digitizing device. In our case, it is a sound card.

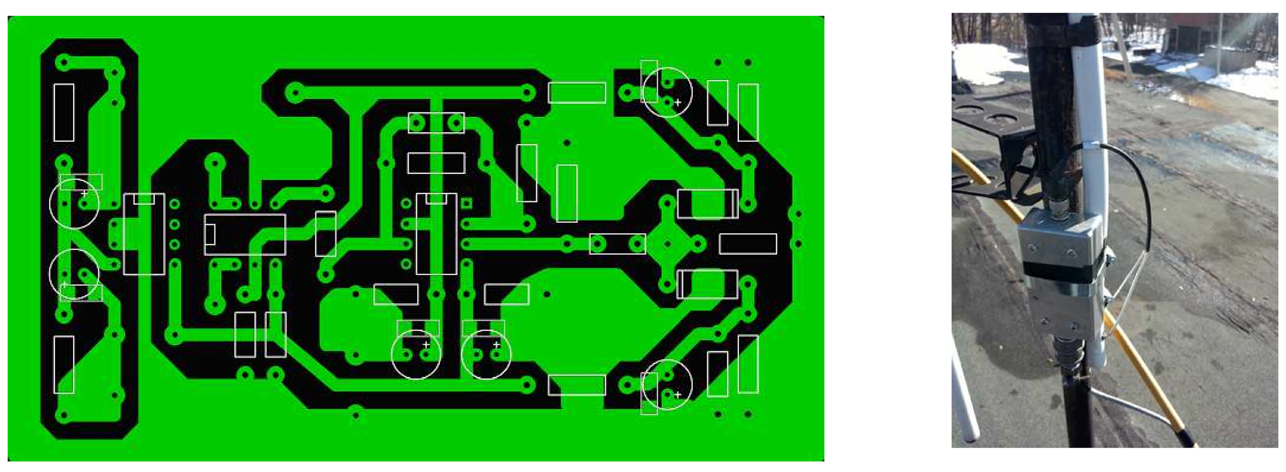


Fig. 2. (a) printed circuit board of the preamplifier; (b) an example of a prepared PA mounted on the antenna.

A flagpole vertical antenna is used to record VLF signals. Such antennas have a large number of different constructions manufactured industrially and handmade without large financial expenditures. The latter criterion is very important since the low cost of a lightning sensor system is of great priority in the development of the whole complex. For example, a ship receiving antenna is applied at Paratunka and Karymshina Geophysical Observatories of IKIR FEB RAS. Such a solution provides good signal reception but the cost and complexity of installation do not correspond to «Lightning sensor system» project. That is why, some works were carried out to build antennas from available materials which characteristics satisfied the requirements for VLF signal registration in the defined range (not more than 100 kHz).

First of all, we studied the way of antenna construction by WWLLN specialists. This method is very simple and may be applied in living environment from available materials. Antenna is a wire put into a plastic tube of a small diameter (15-20 mm depending on the wire thickness). The wire forms a loop on the top. Different kinds of wires, solid and stranded, may be applied. For example a usual wire for local communication networks UTP5, four twisted pairs without a screen, were used in an antenna at a WWLLN station in Singapore. The antenna may be also constructed form a simple plastic tube for hot water. Such antenna was constructed at a WWLLN station at Khabarovsk Geophysical Observatory of IKIR FEB RAS. The walls of such tubes are reinforced with metal, in particular with aluminum alloys. That means there is a metal cylinder inside a tube. It may be used as an antenna. By the way, there is a number of industrial solutions where antenna is made of a metal cylinder. Such an antenna is installed at a WWLLN station at Magadan Geophysical Observatory of IKIR FEB RAS. Antenna is mounted on the roof of a building of a station as high as possible. The length of an antenna is chosen according to the conditions of installation and operation (constructive peculiarities of a building, weather conditions etc.) but not less than 3 meters since its efficiency depends on the length.

VLF sensor software

One imposes on a VLF sensor the following basic tasks: saving received data on remote server; detecting PPSimpulses with given precision; time synchronization of received data; stream identification and classification by various parameters of atmospherics, whistlers, anomalies in received data; etc.

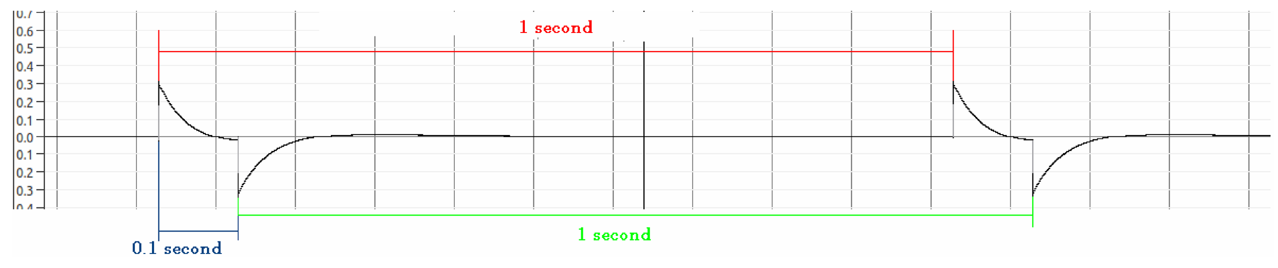


Fig. 3. Sample of the PPS signal.

For time synchronization, one uses a GPS-receiver which, once a second, generates PPS-impulses as shown in Fig. 3 and 4. For stream identification, one implements their cubic spline interpolation with given precision at a mini-computer (Fig. 4 and considers both ascending and descending fronts of a PPS-impulse. Such approach allows to assure the precision of ~8,12 * 10-8 sec for definining the middle of a PPS-impulse ascending front, when using a sound card ASUS Xonar U5 with frequency discretization 192 kHz.

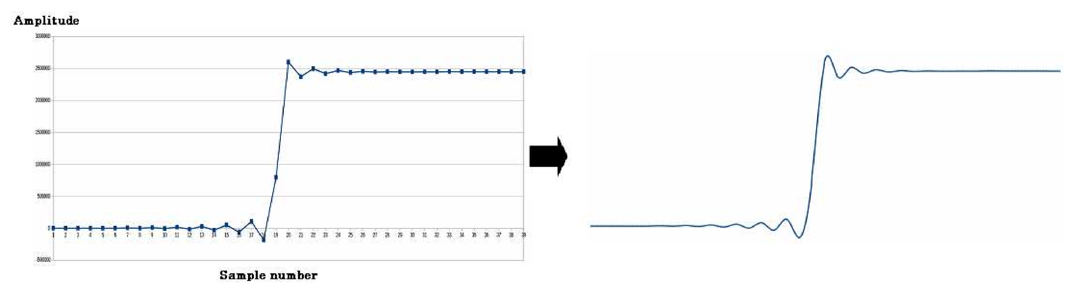
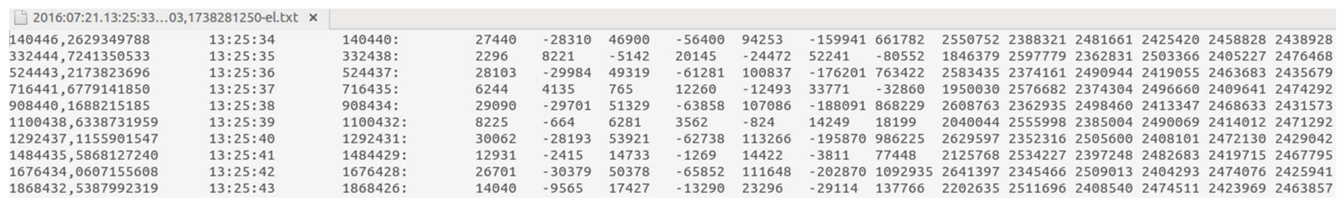


Fig. 4. An example of a cubic spline interpolation of a PPS-impulse ascending front

As PPS-impulses are being identified in stream mode on a mini-computer of the VLF sensor, it is not rational to store the particular PPS-channel at a remote server. Instead, one saves the meta-information of time synchronization into a file (Fig. 5). Each line of the example provided in Fig. 5 contains 16 fields separated by TAB symbol. The first field stores the sample number (double value) of the time start which value written in the second field. The third field stores the number of a sample, starting with which the rest of the line contains 13 digitalized by a sound card values of a PPS-impulse. An example of a spectrogram of a signal received with help of a VLF sensor with a vertical electrical antenna is provided in Fig. 6.

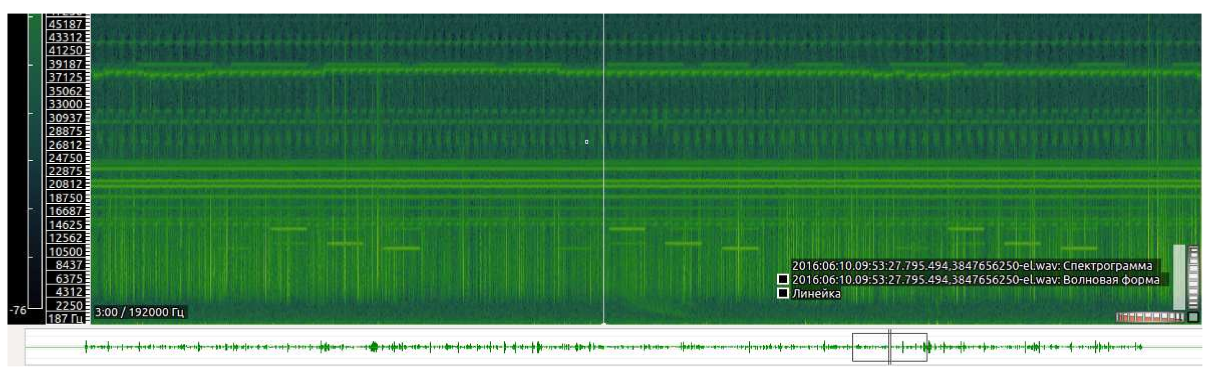


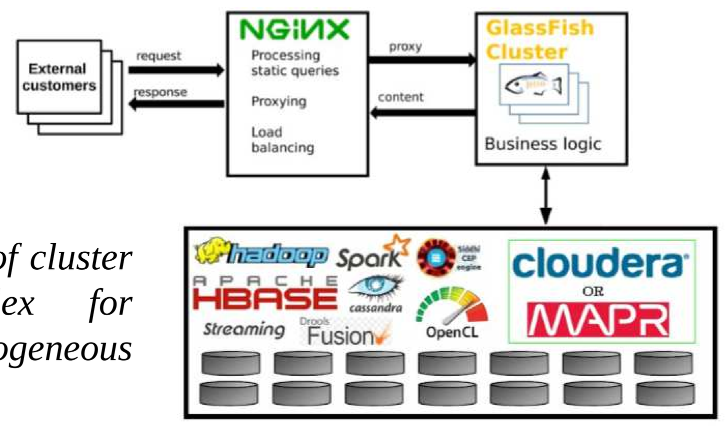
2016:07:21.13:25:33...03,1738281250-el.txt

140446,2629349788	13:25:34	140440:	27440	-28310	46900	-56400	94253	-159941	661782	2550752	2388321	2481661	2425420	2458828	2438928
332444,7241350533	13:25:35	332438:	2296	8221	-5142	20145	-24472	52241	-80552	1846379	2597779	2362831	2503366	2405227	2476468
524443,2173823696	13:25:36	524437:	28103	-29984	49319	-61281	100837	-176201	763422	2583435	2374161	2490944	2419055	2463683	2435679
716441,6779141850	13:25:37	716435:	6244	4135	765	12260	-12493	33771	-32860	1950030	2576682	2374304	2496660	2409641	2474292
908440,1688215185	13:25:38	908434:	29090	-29701	51329	-63858	107086	-188091	868229	2608763	2362935	2498460	2413347	2468633	2431573
1100438,6338731959	13:25:39	1100432:	8225	-664	6281	3562	-824	14249	18199	2040044	2555998	2385004	2490069	2414012	2471292
1292437,1155901547	13:25:40	1292431:	30062	-28193	53921	-62738	113266	-195870	986225	2629597	2352316	2505600	2408101	2472130	2429042
1484435,5868127240	13:25:41	1484429:	12931	-2415	14733	-1269	14422	-3811	77448	2125768	2534227	2397248	2482683	2419715	2467795
1676434,0607155608	13:25:42	1676428:	26701	-30379	50378	-65852	111648	-202870	1092935	2641397	2345466	2509013	2404293	2474076	2425941
1868432,5387992319	13:25:43	1868426:	14040	-9565	17427	-13290	23296	-29114	137766	2202635	2511696	2408540	2474511	2423969	2463857

Fig. 5. An example of the meta-information of time synchronization.

Fig. 6. An example of a spectrogram of a signal received with a vertical electrical antenna.





The architecture of cluster software complex for analysis of heterogeneous monitoring data

Remote sensing of seismic disturbances in the lower ionosphere according to observations of lightning electromagnetic signals in Yakutsk

For the purposes of the azimuthal scan it is necessary to know the direction of arrival of radio signals, so the receiving of signals is carried out by the antenna system consisting of two orthogonal magnetic (loop) antennas, and a vertical electric (rod) antenna. The signals from magnetic antennas are used for determining the angle of the arrival direction, and from an electric antenna - for eliminating azimuth ambiguity (Fig. 7). Since signals must pass over the area of epicenters, the signals from the respective distances to their lightning sources are selected. Estimation of the distance to the source of the signal (lightning discharge) is carried out according to the frequency characteristics of signals and calibration of this method according to the other lightning detection systems (especially according to the global WWLLN system. Unlike radio signals, when using lightning signals – atmospherics, only the amplitude variations can be considered. At the same time, due to the large variation of the amplitudes of atmospherics, the values averaged over one hour period are used.

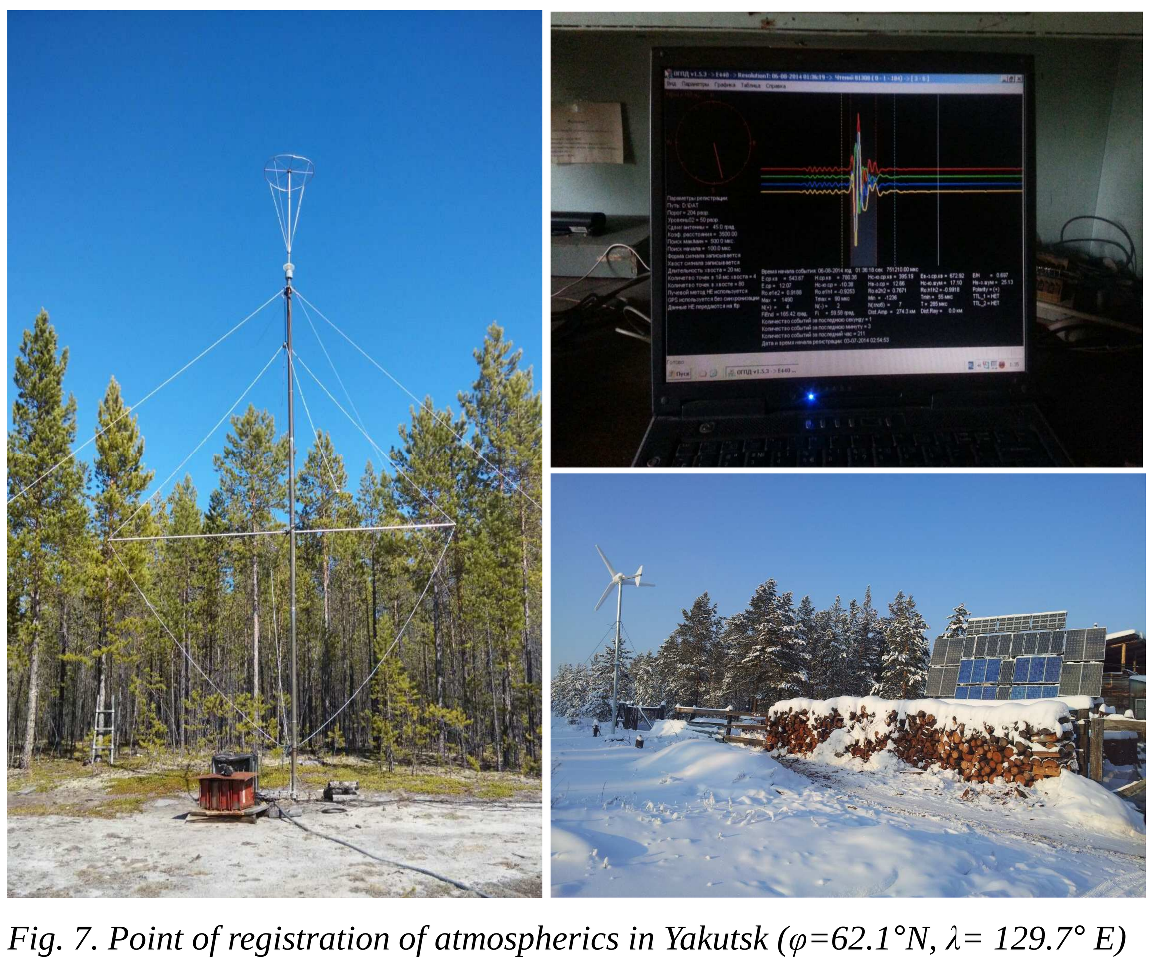


Fig. 7. Point of registration of atmospherics in Yakutsk (φ=62.1°N, λ= 129.7° E)

The method of analysis is as follows: The azimuth and distance to Yakutsk are determined for each selected earthquake. For an initial analysis, we select atmospherics, the propagation paths of which are located at a distance not more than the fifth Fresnel zone from the epicenter, and the distances of their thunderstorm sources are larger than the distance to the earthquake. To calculate the Fresnel zones, we accepted 10 kHz as the center frequency of the spectrum of atmospherics. The average amplitude of atmospherics registered during an hour is determined (about and more than 1000 atmospherics are as a rule registered). The rms amplitude values are averaged, since signals are received in a broad band. The signal amplitudes have been led to the amplitude of one distance (the distance to an earthquake source) by using the dependence of the damping factor from distance (inversely proportional to distance) in a first approximation. This procedure is performed in order to decrease the effect of smearing and the displacement of signal sources (lightning discharges) from day to day. Azimuthal scanning with a shift of one–two Fresnel zones is subsequently performed in order to specify the effective dimensions of the disturbed zones in the ionosphere. The earthquake characteristics were taken from the catalog (neic.usgs. gov/neis/eglists/significant.html).

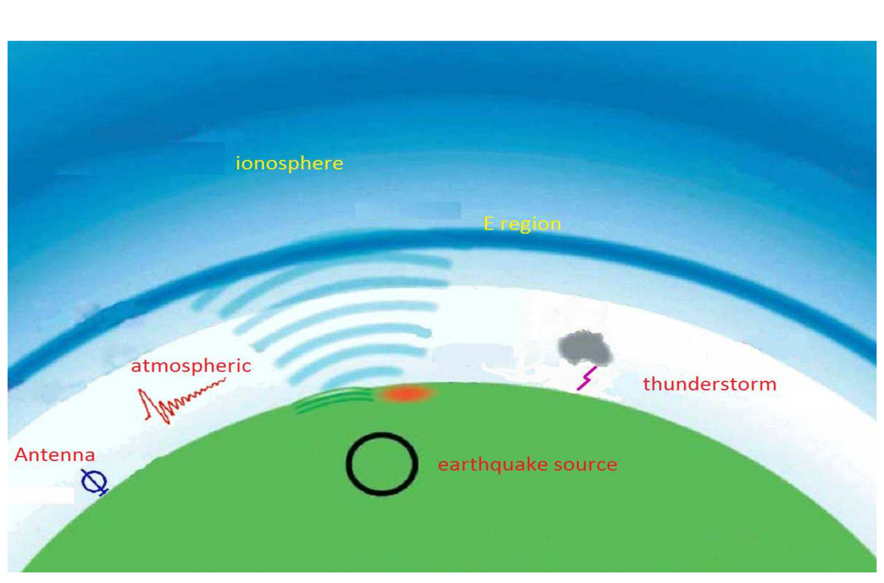


Fig. 8. Remote monitoring scheme of areas of ionosphere above the earthquakes using electromagnetic signals from lighting discharges.

Conclusion

The registration of lightning and whistlers registration is actual today. The results of investigations may be used in meteorology and as some indicators of the lower ionosphere conditions (storm activity and tweaks), the magnetosphere (whistlers), solar activity, magnetic storms, and etc. Variations of lightning signal parameters may serve as an indicator of ionospheric disturbances, which may be associated with geomagnetic activity, solar flares and lithospheric processes. And these fluctuations can be used as one of methods for searching of earthquake precursors. In this work VLF detector may become the main for distributed analysis system and monitoring of thunderstorm activity.

The study was supported by RFBR, research projects No. 15-45-05005 r_vostok_a, No. 15-45-05135 r_vostok_a.