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POSSIBLE EFECTS OF THE LIGHTNING CENTERS IN WHISTLER RATES IN KAMCHATKA

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The paper investigates possible sources of Kamchatka whistlers in March and September 2013. Applying the data from WWLLN and AWDANet worldwide networks, it is shown that statistically significant sources may be located in the global lightning centers.

Key words: Whistlers, VLF radiation, magnetosphere.

Introduction

Every lightning discharge occurring in the Earth atmosphere forms an electromagnetic pulse distributed in a wide frequency range. In particular, this pulse appears in the very low frequency range (VLF) where it is called an atmospheric [1]. Besides the atmospherics, signals having a characteristic saber-like form in spectral-time diagram also appear in VLF range radio signals. An example of such a signal is shown in Fig.1.

An acoustic analogue of a signal with such a spectrum is whistle, so they are called whistling atmospherics or whistlers. Just like atmospherics, whistlers are associated directly with lightning discharges.

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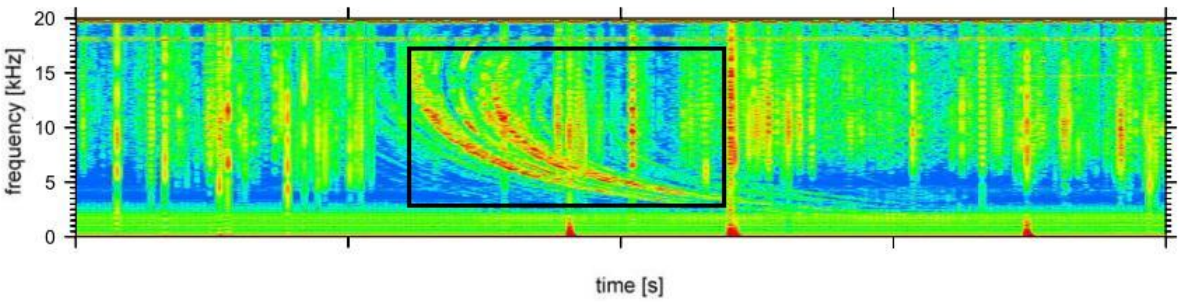

Fig. 1. Whistler typical imaging in spectral-time diagram of VLF signal.

The mechanism for whistler generation was suggested in the classical paper by Storey [2]. According to this theory, an atmospheric with the power of $\backsim 20$ GV initiated by a lightning discharge propagates in the Earth-ionosphere waveguide. It almost does not dissipate, and may pass considerable distances with slight deviation of $\backsim 1$ dB/Mm. However, some part of the atmospheric energy may penetrate through the ionosphere and enter the magnetosphere. In irregular anisotropic magnetospheric plasma, the electromagnetic wave undergoes frequency dispersion. As a result, pulse is transformed into a complicated signal with saber-like frequency-time characteristic determined by field line strength and plasma density along the trajectory in the magnetosphere. The fact that the whistler form depends on plasma distribution and field intensity makes it a natural marker of the Earth plasmasphere state and an interesting object in cosmic weather system.

According to the described mechanism, the most possible lightning source of a whistler may be located either in the vicinity of the point of its registration or in the vicinity of a magnetically conjugate point. In the first case, a whistler which passed the magnetospheric channel an even number of times is recorded; in the second case, a recorded whistler passes the channel uneven number of times. Nevertheless, whistler drift in the magnetosphere between different waveguides and registration of "outside"whistlers are theoretically possible [1].

The favorable conditions for VLF signal penetration into the magnetospheric channel are in high latitudes where field lines are almost vertical and field intensity is higher [3]. We should also note that whistler drift between the tubes is possible if a wavelength is comparable with a duct width. [4, 5]. Thus, in spite of the fact, that most of the lightning occur in the low latitude regions (tropics and subtropics), whistler sources are mostly located higher along the geomagnetic latitude. We may even suppose that there is a cutoff latitude for whistlers at the level of about $\pm 16^\circ$ of the latitude [6, 7].

While the mechanism for whistler generation does not arouse a discord among the specialists, lightning source region parameters and geometry are debatable problems. It is the most natural to suppose that the source must be symmetrical relative to the entry point into the magnetosphere, and the penetration efficiency must decrease with distance from this point. Nevertheless, it has been stated in a number of papers that the penetration efficiency is shifted relative to the entry point in the direction of the geomagnetic pole [8, 9]. Also, there is no one opinion about the region dimensions.

The present paper investigates the question, if "outside"whistlers are recorded in Kamchatka.

Initial data

The detailed information on the distribution of lightning discharges occurring on the Earth is contained in the databases of the World Wide Lightning Location Network (WWLLN). This network was founded and developed by the specialists of Washington University, Seattle, USA (http://webflash.ess.washington.edu/).

The network gives quite an accurate display of global lightning activity. It records discharges with heavy currents and registers the first stroke in a multi-flash. For every stroke, time and geographical coordinates are recorded, where time and space distributions are about 3×10^{-5} s and 10 km, correspondingly [10]. The network includes about 80 receiving stations determining lightning location all over the globe, located at paired distances from several meters to 10,000 km. Distribution of the world wide network stations is shown in Fig. 2.

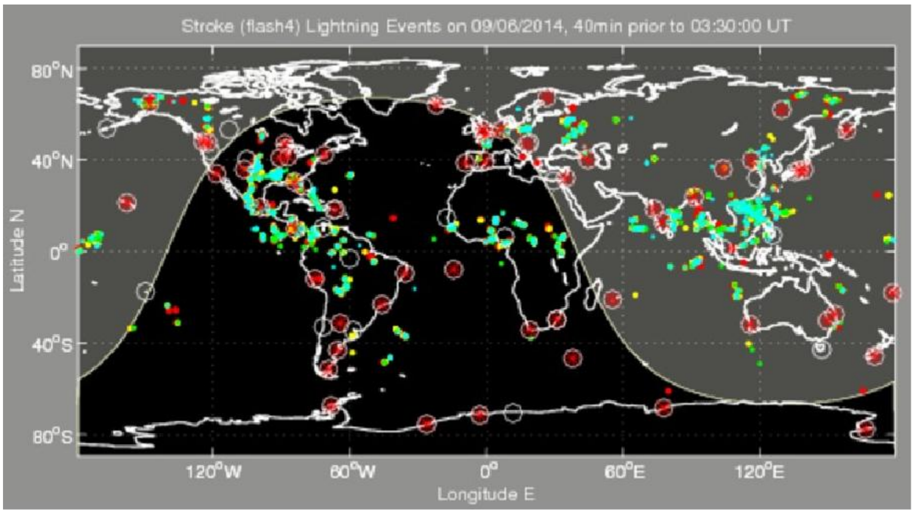

Fig. 2. Distribution of WWLLN network receiving stations. The image is taken from the site http://webflash.ess.washington.edu/

WWLLN identifies cloud-ground (CG), cloud-cloud (CC), and inter-cloud (IC) lightning discharges, but does not distinguish them [10]. Comparison of discharge detection efficiency by WWLLN and by a number of regional networks showed that WWLLN allows us to obtain representative information on lightning activity in planetary scale [11, 12].

The receiving stations register radiation arriving via the Earth-ionosphere waveguide with the maximum at the frequency of 10 kHz (30 km wavelength). To locate a lightning, three stations surrounding this lighting are enough. Spectrograms are updated every 10 minutes on the page http://webflash.ess.washington.edu/spectra.html. One of the stations of this network is installed at the Institute of Cosmophysical Research and Radio Wave Propagation (IKIR) FEB RAS in Kamchatka. WWLLN data allow us to make a time sequence, an ascending sequence of lightning stroke random moments, for a chosen geographical region.

Automatic Whistler Detector and Analyzer systems' Network (AWDANet) was developed for global whistler detection on the Earth. This network was founded and developed within several international projects under the direction of the specialists from Eotvos University, Budapest, Hungary [13]. AWDANet has been recently extended by a far-eastern Karymshina station, Kamchatka, Russia (LAT 52.83, LON 158.13, L=2.13). The activity of whistlers recorded in Kamchatka is unusually high. During the first five months of the operation, more than 200,000 whistlers were recorded. AWDANet system was completed by PLASMON automatic analyzer (http://plasmon.elte.hu). It is based on the recently developed model for whistler inversion [14], that allowed us to make the process of whistler analysis automatic not only for events with a single whistler arrival but also for complex analysis of multiple path propagating whistler groups. Distribution of AWDANet stations is shown in Fig. 3.

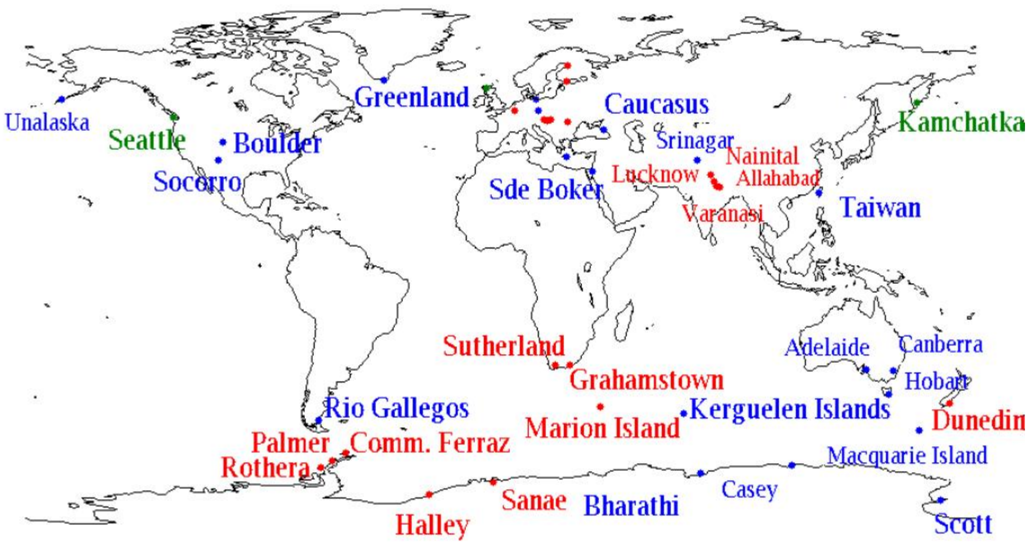

Fig. 3. Distribution of AWDANet receiving stations. Red and green dots correspond to active stations. Blue dots are the stations planned to be installed. The image is taken from the site http://plasmon.elte.hu

To detect whistlers automatically considering regional peculiarities of their dispersion curve, a detection algorithm was developed at IKIR FEB RAS [15, 16], the basis of which is a method of two-dimensional correlation of an initial signal spectrum and a model signal spectrum. The system based on this method consists of a detector and a determining factor, an adaptive threshold. The detector performs the two-dimensional correlation of signal fragment spectrum in a 4-second time window. The adaptive threshold is some average value. If its «normal level» is exceeded, a preliminary conclusion is formed that the signal contains a whistler. The detection algorithm is realized in the neural network operating automatically.

Analysis technique

The statistical relation between Kamchatka whistlers and lightning discharges from a given geographical region was analyzed by the correlation method.

Whistler time series W_t was composed, it is a number of whistlers registered per a period of time $[t; t+\Delta t]$. For the given geographical region, lighting discharge time series L_t, registered in this region for the same period of time, was composed from WWLLN network database. The sampling interval Δt was 1 min and 15 min for two variants of comparison. Since the sampling interval was larger than the time of signal propagation from the lightning source to the point of whistler registration even for the case of multiple propagation in the magnetosphere, cross-correlation between the series was calculated only for the time zero shift.

The characteristic peculiarity of the analyzed time series is the presence of large spikes, the number of events may sharply change in neighbor time samples from zero to hundreds. It is known that the usually applied Pearson correlation coefficient is very sensitive to such spikes, just like any other characteristic based on average values. Moreover, if the correlation coefficient is small, then it is possible to conclude that series are independent only in the case of Gaussian statistics that is not correct for the analyzed series due to the presence of large spikes. In the case of strong but considerably nonlinear relation, the correlation coefficient may be small and even equal to zero.

To repress the effect of large spikes in the investigation of the relation between whistlers and lightning, data are sometimes roughened to Boolean values. In this case, if the interval contains discharges or whistlers, the time series sample is assigned the value 1; in other cases, it is 0 [17, 18].

Another way to obtain robust estimations is the application of real, not Boolean, values of time series with calculation of Spearman rank correlation coefficient. It is the correlation between value ranks in data series and it is stable to its monotonous transformations [19]. In particular, sharp spikes do not affect it. It is supposed that application of rank correlation allows us to obtain reliable statistical conclusions, from one side, and not to loose the information in Boolean roughening, from the other.

Analysis results

Two time intervals were under the analysis: 1-11 March 2013, and 1-30 September 2013. In the first case, rank correlation was estimated; in the second case, series were roughened to Boolean values.

Consider the analysis results for each case in detail.

In the first case, we carried out lightning sampling to make a series L_t for large geographical regions: Kamchatka (LAT 43N-63N LON 150E-170E), Australia (LAT 25S-45S LON 140E-160E), American (LAT 0N-45N LON 40W-110W), African (LAT 10S-20N LON 15W-45E), Indonesian (LAT10S-30N LON 100E-130E) lightning centers. Sampling interval is 15 min.

Fig. 4-5 show intensity rate series of whistlers and lightning discharges, normalized to the maximal number of events for the analyzed period for magnetically conjugate points.

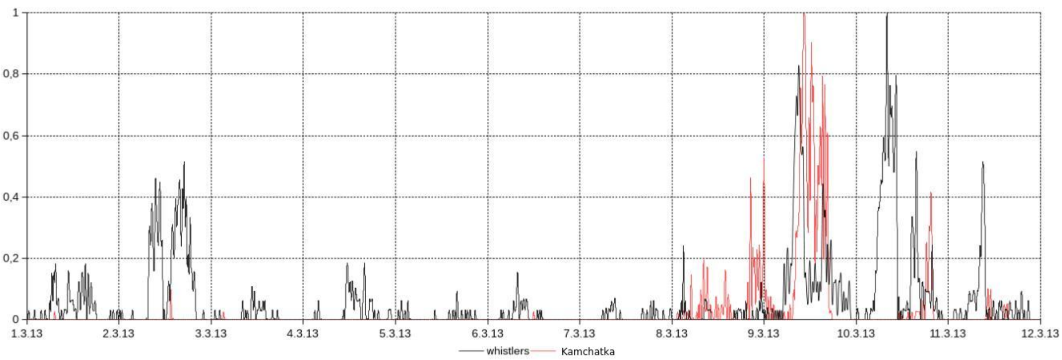

Fig. 4. Intensities of whistlers in Kamchatka and lightning discharges in Kamchatka.

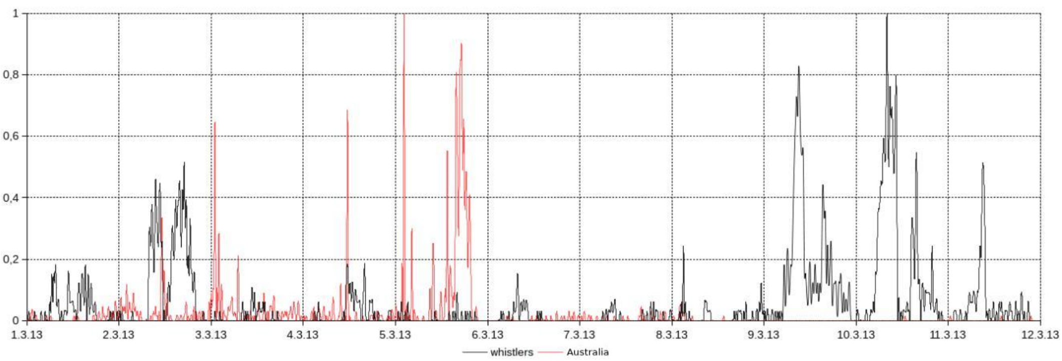

Fig. 5. Intensities of whistlers in Kamchatka and lightning discharges in Australia.

Visual comparison of these series shows a certain relation between the rates. For example, there is a clear relation of the sharp increase in whistler intensity on 9 March with Kamchatka lightning. Further correlation analysis determined an spike of whistler number on March 2 which coincides with the increase in discharge intensity in America, Africa, and Indonesia. It is difficult to separate them visually. Consider the results of calculation of rank correlation shown in Table.

Table

Rank correlation between whistler and lightning discharge rates

Date, time	Kamchatka	America	Africa	Indonesia	Australia
01.03.13 5:45-9:15	0.25	**0.37/0.2**	-0.44	-0.35	-0.16
01.03.13 9:45-13:00	–	-0.64	**0.42/0.15**	0.06	-0.19
01.03.13 13:15-19:00	–	-0.31	-0.23	-0.38	-0.38
02.03.13 7:30-12:15	–	-0.54	-0.34	-0.34	-0.34
02.03.13 12:30-21:00	-0.06	0.24	**0.62/0.0001**	**0.43/0.01**	-0.28
03.03.13 8:00-15:00	–	0.06	0.06	-0.37	-0.05
04.03.13 10:45-20:30	–	-0.26	-0.61	0.18	**0.35/0.03**
05.03.13 14:30-22:00	–	-0.21	-0.05	0.23	0.34/0.1
06.03.13 5:30-14:00	-0.17	**0.2/0.25**	-0.08	-0.26	-0.3
08.03.13 2:15-5:15	0.05	-0.04	**0.46/0.15**	-0.62	0.11
09.03.13 4:45-13:45	0.08	-0.57	0.14	-0.65	–
09.03.13 14:15-23:15	**0.57/0.0005**	0.005	-0.34	0.26	0.06
10.03.13 4:00-13:00	-0.25	-0.47	0.29	-0.29	-0.17
10.03.13 13:15-22:15	**0.42/0.01**	0.02	0.14	0.09	–
11.03.13 5:00-11:30	-0.59	-0.36	**0.56/0.005**	0.09	–

The first column contains time intervals with increases in whistler rates, and the following ones contain the correlation coefficient values between the whistlers and lightning discharges during these intervals. The significant levels of positive correlation are marked by bold type and splashes separate the significance levels on which the hypothesis on non-correlatedness is rejected.

It is clear that there were significant positive correlations of whistler rates with lightning discharges in Kamchatka (9 and 10 March), in Australia (4 and 5 March), in the American source (1 and 6 March), in African source (1, 2, 8, and 11 March). It is difficult to attribute the spikes on 3, 9 and 10 March to one of the given sources; their sources are likely to be located in other regions.

Now, consider the analysis results for the second time interval on 1-31 September 2013.

The analysis was carried out according to the method described in the paper [17]. The Earth surface was separated into the regions of 3×3 degrees, and a time series L_t of lightning discharge number per 1 min was formed for every region. The same time series W_t was composed for Kamchatka whistlers. Then correlation coefficient between the series, roughened to Boolean values, was calculated.

The hypothesis on zero correlation for the considered series with the significance level $\gamma = 0.05$ is rejected for the correlation sample value of 0.011. Fig. 6 illustrates the correlation coefficient distribution for those elements of the grade grid, where its value exceeds the significance limit.

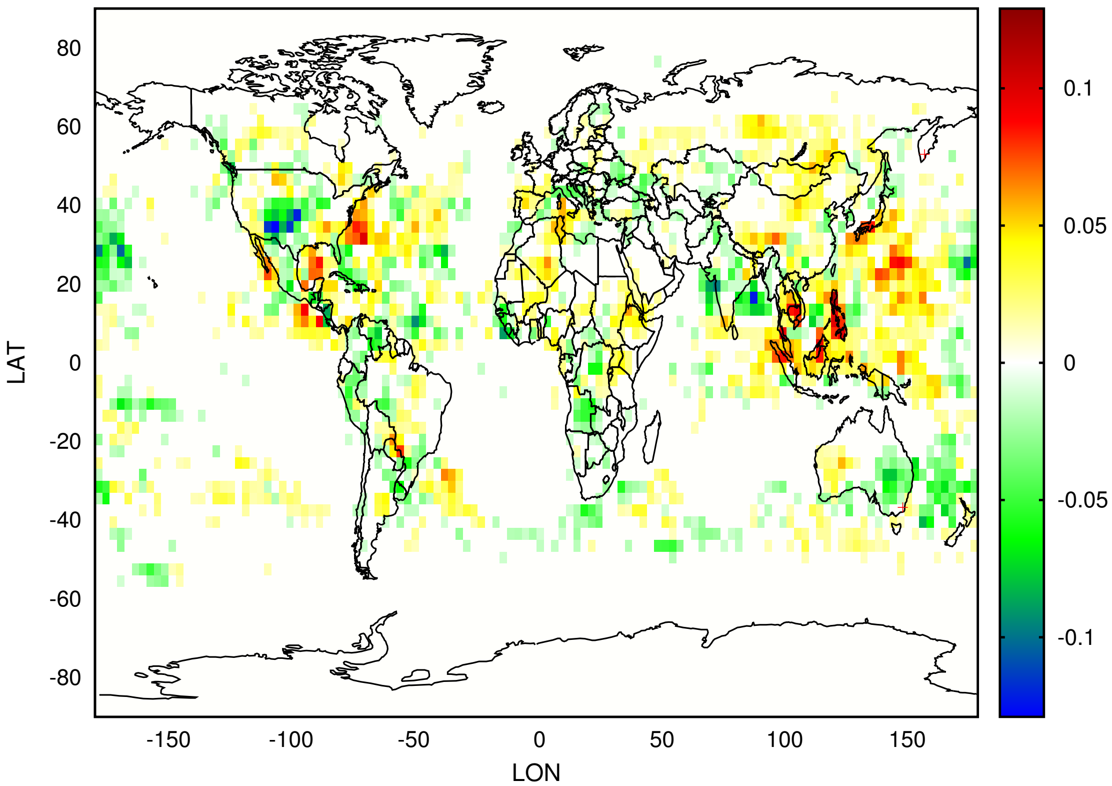

Fig. 6. Distribution of correlation coefficient between the series of Kamchatka whistlers and lightning discharges on the grade greed of 3×3. Red rhombs indicate the location of Kamchatka observatory (LAT 52.97N LON 158.25E) and the magnetically conjugate point in Australia (LAT 36.77S LON 149.40E). The cell color corresponds to correlation coefficient values. In white colored cells, the correlation is insignificant.

It is clear from this distribution that during the considered time interval, correlation between the Kamchatka whistlers and lightning in the Australian conjugate point was not observed. Nevertheless, there is correlation between the whistlers and the activity of Indonesian and American lightning centers.

Conclusions

Analysis of whistler intensity series for the periods 1-13 March 2013, and 1-30 September 2013, recorded in Kamchatka, showed that the registered signals may have lightning sources both from "Kamchatka"magnetic field tube and from other regions. Kamchatka and Australia lightning did not dominate as it might be expected. The possible explanation of this fact is that lightning intensity in American, African, and Indonesian sources was significantly higher during the considered periods than that in Australia and, especially, in Kamchatka.

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