Jacobs, J. A.: Yes, although oceanic islands with a sharp sea-land interface would not be a good subsitute for an inland station with known regular geology.

Campbell, W. H.: This question concerns your discussion of the Victoria-Ralston experiment which you report as having been carried out to indicate the effect of the ocean on the direction of the pulsation fields. You, of course, realize that the east station was closer to the auroral zone. It seems that such proximity would affect your conclusions. Why was it not considered?

Jacobs, J. A.: The 3 stations, Vectoria, Westham Island, and Abbotsford are all close together and here approximately the same geomagnetic latitude. My main results concern differences between these three. Ralston is, as you remark, closer to the auroral zone and this would affect results from that station.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-1B-P3. Fine Structure of Magnetic Storms in Respect of Micropulsations ($T<20$ sec)*

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The investigations of magnetic storms allowed to obtain many interesting conclusions concerning both the peculiarities of the development of this most violent disturbance of the Earth's field and many important questions such as the structure of the high atmosphere, development of the ring-current, the scale of the C-F cavity, *etc.*[1)-6)]. Most of these investigations were carried out using standard magnetic records. Only during the last decade due to the wide growth of interest to pulsations in the magnetic field and Earth currents began the observations with greater time scale and sensitivity[7)-14)]. It was realized that in these rapid variations are mirrored different fine processes which take place at the border of the C-F cavity, as well as in the whole body of the high atmosphere including the ionosphere[7)-14)].

Therefore it is of undoubted interest to use the pulsations records in the analysis of the microstructure of magnetic storms. As the first results show this analysis reveals many new features of magnetic storms development. The new facts may and have to be used in the theory of magnetic storms, and in discussions of other problems such as the structure of solar corpuscular streams, trapping of the charged particles by the magnetic field and in the course of investigations of different geophysical phenomena in the high atmosphere.

Experimental Data

The results given below were mainly obtained in the course of processing of ultra-quick run earth-current records at stations located in the Arctic, the Antarctic and in the middle latitudes of the Northern hemisphere ($\lambda \sim 120°$)[15)]. The records were conducted 24 hours running, with time scale 1/2 mm in a second. Pulsations with periods from fractions of a second (which can be still recognized on the records) to 15-20 seconds were analyzed. The frequency response of the installations did not allow to record pulsations with greater periods and the latter

* The paper entitled "The Connection of *pc* and and *pt* Pulsations with Magnetic Storms", presented by V.A. Troitskaya, I.I. Rokityansky, K.Yu. Zibin, R. V. Schepetnov and D. A. Rokityanskaya, is read partially by Troitskaya as a part of this paper.

were investigated using other records (not described here). The investigation of the magnetic storms fine structure in this spectral range was begun already in 1957[16,17], but the method of analysis and the classification of pulsations changed significantly still that time. In this paper for the first time are summarized the results of processing of 30 magnetic storms, conducted in the frames of the following classification.

1. Pulsations of the relatively regular form among which the main types are the continuous pulsations (*pc*) of small period ($T{\sim}8$–20 sec) and the pulsations of the pearl type (*PP*) with periods from fractions of a second to 6–8 sec.

2. Pulsations of the characteristic irregular form with different degree of superposition of pulsations of smaller periods (*sip*)-short irregular pulsations ($T{\sim}2$–15 sec).

3. Bursts of pulsations—sudden changes of oscillatory regimen of pulsations. The bursts were divided in two types.

a) Bursts with superimposed pulsations of short period (2–6 sec) which represent the sequence of oscillations typical for the fine structure of bays or pulsation trains (*pt*).

b) Bursts of pulsations representing the amplification of oscillations of *pc* type ($T{\sim}$ 8–15 sec), which are characteristic also for the fine structure of *SSC*.

4. Intervals of pulsations diminishing on periods *IPDP*[18,19] which occur as a rule in the interval of the maximal development of the storm.

Special attention in this investigation was given to the differences in the fine structure of the *SSC*, of the initial and of the main phases of the storm. Besides the analysis of the storm, the general state of the magnetic field during 48 hours before the storm was investigated. Examples of schemes of such analyses for two storms (13/IX and 29/IX-57) are given in the supplement.

Pre-Storm Period

The analysis of the July 1959 magnetic storms has shown, that before the beginning of two storms (11/VII and 15/VII) occurred series of *PP* pulsations, the presence of which could not be recognized on ordinary slow records neither directly nor indirectly (as a fine structure of some macroscopic disturbance). These series of *PP*-pulsations showed correlations with injections of solar cosmic rays observed by means of balloons in USSR and USA[19].

It seemed to be of great interest to investigate systematically how often does this phenomenon occur before the storms, what is the usual time difference between the beginning of the storms and the series of these pulsations, what typical duration have these series, what is their spectral distribution on periods, etc.

This analysis was conducted for the period of 48 hours before the storms. In this paper are given the results of investigation of the 12 hours pre-storm period. Excitation of *PP* at one of the stations was counted as one case.

From 30 investigated pre-storm periods, 28 storms had *PP* excited in the intervals 0–12 hours before the storm. Most frequent are

Fig. 1. The distribution of series of *PP* before the storms on hours counted from the beginning of the storm. (0–12 hours)

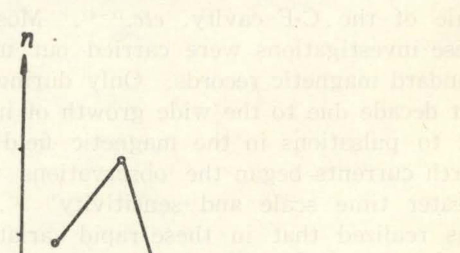

Fig. 2. Duration of series of *PP* observed before the storm.

cases, when *PP* are observed some scores of minutes—2 hours before the beginning of the storm (Fig. 1). The duration of *PP* series is as a rule 10-15 min. and seldom exceed 2 hours (Fig. 2). Fig. 3 shows the spectral distribution of *PP* on periods for all cases revealed in 0-12 hours pre-storm interval.

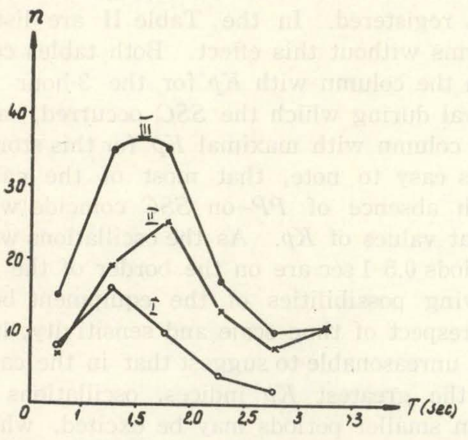

Fig. 3. Distribution of *PP* observed before the storm on periods
I-The curve for middle latitude stations.
II-The curve for high latitude stations.
III-Sum of the curves I and II

The curves for middle (1) and high latitude (2) stations are given separately. The most interesting fact is the displacement of the curve (2), towards the longer periods. Similar result was obtained in (18). For the investigated pre-storm interval several cases were discovered, where *PP* pulsations occurred with different periods simultaneously at different stations. These new regularities show that *PP* are an example of electromagnetic oscillations in the Earth's field with latitude dependence of their periods. This dependence reveals itself in their different spectral distribution on periods in different latitudes and in some, although not very frequent, cases of simultaneous *PP* excitations of different periods.

Besides the *PP*, short irregular pulsations (*sip*), continuous pulsations and some other mixed types of pulsations are observed during the pre-storm period.

The analysis of these pulsations gives evidence that in many cases they begin at high latitude stations several hours before the storm. That means, that the corpuscular streams exciting them, commence to inject in high latitudes well in advance of the main stream causing the magnetic storm.

SSC of the Magnetic Storm and Its Initial Phase

SSC. The analysis of the *SSC* fine structure in addition to the already known facts allowed to establish the following: *SSC* consists (in the period range less than 20 sec) of a series of pulsations ($T\sim$8-15sec) diminishing in amplitude and lasting in the average 1.5-3 minutes. The oscillatory regimen of this phenomenon is better expressed at the sunlit side of the Earth[16),19),20-23)]. The last interesting results of *SSC* investigations are the discovery of the latitudinal character of *SSC* propagation and the revealing of *PP* with shorter than usual periods superimposed on the *SSC* oscillations and observed also in the first minutes of the storm.

The special analysis of 18 *SSC*'s carried out on materials received at Soviet and some other stations, showed, that in 17 cases, the first movement due to the *SSC* was registered either in the Arctic or in the Antarctic. It is important to stress that usually the first movement is revealed in the sunlit hemisphere[24)]. Similar results for 3 cases of *SSC* are described in (25). The differences in the moments of *SSC* beginnings have the order of 10-40 sec. The precision with which can be given the moments of *SSC* beginnings is determined mainly by the steepness of the front of the first movement. Usually the first movements of *SSC* on a rapid time scale are not steep enough and the precision provided by the time service at the stations (1/2 sec or less) cannot be properly used. Nevertheless the obtained experimental results seem to show, that the shock-wave connected with the front of the corpuscular stream arrives first of all into the sunlit polar regions[4)].

In the course of *SSC* analysis it was discovered, that *PP* of small periods are superimposed on the *SSC* oscillations. These small *PP* are revealed in some cases on the records of many stations, and in the others on the records of 1-2 stations (See Table I). The investigations showed, that from 35 cases of *SSC* analysed on records of a net of stations in this respect, 21 showed *PP* superimposed on the *SSC*. The spectral distribution of these *PP* on periods is presented in Fig. 4. For comparison, on the same figure is given the distribution of *PP* revealed in the time interval 0–12 hours before the storm. The curves show that at the beginning of the initial phase of the magnetic storms, when the corpuscular stream is stopped by the magnetic field and consequently the magnetic field is compressed, a sharp diminishing of *PP* periods is observed. In the Table I are given some data concerning the storms with *PP* superimposed on *SSC* at different stations. In the last column the number of given values of *T* show also the number of stations at which this phenomenon was registered. In the Table II are listed storms without this effect. Both tables contain the column with *Kp* for the 3-hour interval during which the *SSC* occurred, and the column with maximal *Kp* for this storm. It is easy to note, that most of the cases with absence of *PP* on *SSC* coincide with great values of *Kp*. As the oscillations with periods 0.5–1 sec are on the border of the resolving possibilities of the equipment both in respect of time scale and sensitivity, it is not unreasonable to suggest that in the cases of the greatest *Kp* indices, oscillations of even smaller periods may be excited, which we simply cannot detect with the present equipment. This tendency of the diminishing of *PP* periods with the increase of *Kp* seems really to exist.

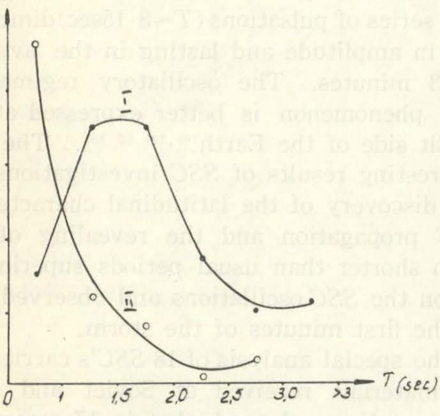

Fig. 4. Distribution of *PP* on periods
I–*PP* superimposed on *SSC*
II–*PP* registered before the storm

Table I. Storms with *PP* on *SSC*.

No.	Storm			*SSC*	Kp_{max}	*K* at *SSC*	*T* (*PP*)
1	1–2	IX	1957	$03^h 15^m$	9	6_0	*T*—1–1.5 sec
2	13	IX	1957	$00^h 46^m$	9	8_-	*T*—0.8, 1, 1, 1, 1–1.5 sec
3	21	IX	1957	$10^h 04^m$	7	7^+	*T*—0.5-1, 0.8–1, 1.2–1.5 sec
4	6–7	VI	1958	$00^h 44^m$	5	7_0	*T*—1, 1, 1, 1 sec
5	28	VI	1958	$17^h 42^m$	8	7_0	*T*—0.6-1-2, 0.8–1, 1, 1, 1.5, 1.5–2 sec
6	21	VII	1958	$16^h 36^m$	6	7_-	*T*—0.7, 0.7, 0.7, 0.7, 0.7, 0.8 sec
7	17	VIII	1957	$06^h 22^m$	7	6_0	*T*—0.7, 0.7, 0.7, 0.7, 0.8 sec
8	22	VIII	1958	$02^h 27^m$	6	6_-	*T*—0.8-1-1.5, 1, 1.5 sec
9	24	VIII	1958	$01^h 39^m$	8	8_-	*T*—0.6, 0.7, 1, 1 sec
10	27	VIII	1958	$03^h 03^m$	7	6_0	*T*—0.5-0.7, 1, 1, 1–2 sec
11	3–5	IX	1958	$08^h 42^m$	7	5_+	*T*—1, 3 ssc
12	25	IX	1958	$04^h 08^m$	7	6_0	*T*—1 sec
13	4	XII	1958	$00^h 35^m$	7	4_-	*T*—1.5–3 sec
14	25	II	1959	$06^h 54^m$	7	6_+	*T*—1.5–2 sec
15	26–27	III	1959	$08^h 42^m$	8	6_+	*T*—1.5 sec
16	3–5	IX	1959	$21^h 56^m$	7	7_0	*T*—1, 1, 1, 1, 1 sec
17	27	VI	1960	$01^h 48^m$	7	7_-	*T*—0.8–1, 1 sec
18	14	VII	1960	$04^h 48^m$	6	4_-	*T*—1–1.5, 1.5, 1.5, 1.5 sec
19	24	X	1960	$14^h 51^m$	8	2_0	*T*—0.5-1-2, 1.5–2, 1.5–2, 1–1.5 sec
20	12	XI	1960	$13^h 32^m$	9	5_0	*T*—2–2.5 sec
21	15	XI	1960	$13^h 33^m$	8	6_0	*T*—0.8–1 sec

Table II. Storms without *PP* on *SSC*.

No.	Storm			*SSC*	Kp_{max}	*K* at *SSC*	Comments
1	2–3	IX	1957	$02^h 36^m$	9	9_-	
2	29	IX	1957	$00^h 15^m$	9	8_0	
3	4	IX	1957	$13^h 00^m$	9	8_+	
4	22	IX	1957	$13^h 45^m$	8	8_0	
5	11	II	1958	$01^h 26^m$	9	9_0	
6	8	VI	1958	$07^h 41^m$	9	7_+	
7	24	X	1959	$07^h 30^m$	7	7_-	
8	11	VII	1959	$16^h 25^m$	7	7_-	
9	15	VII	1959	$08^h 02^m$	9	8_+	
10	17	VII	1959	$16^h 38^m$	9	8_+	
11	31	V	1958	$16^h 52^m$	8	4_+	
12	16	VIII	1959	$04^h 04^m$	8	4_+	
13	2–3	IV	1960	$23^h 12^m$	7	4_+	
14	4	IX	1960	$02^h 30^m$, $11^h 45^m$	8	4_-, 7_-	

Summarizing the above-mentioned facts we can say that *SSC* revealing itself as the rise in the *H*, present a complex phenomenon consisting of a series of oscillations with periods 8–15 sec with superimposed *PP**. It seems that the periods of *PP* depend on the pressure of the corpuscular stream on the Earth's magnetic field. As regards the old question about the velocity of *SSC* propagation, the obtained results show that this signal comes first into the sunlit polar region and then propagates about the Earth in 10–40 sec. It can be suggested that the main oscillatory regime of *SSC* is due to the processes occurring at the border of C-F cavity. On the other side the *PP* are probably the result of oscillations excited by the particles which were injected and trapped by the magnetic field of the Earth. The fact of injection of charged particles into the Earth's atmosphere coinciding with *SSC* was discovered for the first time for the storm 27–18/VI-1960[26]. It is interesting to note that on the *SSC* of this storm were superimposed *PP* with periods less than 1 sec (in Petropavlovsk).

The Initial Phase (*IP*) of the Magnetic Storm. What is the characteristic for the *IP* of the magnetic storm in respect of pulsations?

The systematic analysis has been only begun, but the first conclusion is the following: During the first phase of the storm dominate one or other oscillatory regimen without changes, without bursts. In the most clear form the *IP* was expressed in the storm of 29/IX-57, when it lasted about 12 hours. During all this period, at all stations *pc* with periods 10–20 sec were observed. Of course, during the *IP*, bursts can be observed also, but as a rule, they are not followed by a change in the oscillatory regime but mean mainly the amplification of the amplitude. The fine structure of these bursts resembles the fine structure of *SSC*. During the *IP*, the *PP* are also rather frequently observed. If we consider *PP* as a result of injections of fast particles, we are drawn to the conclusion that the injections of charged particles into the high atmosphere and their trapping by the magnetic field occur not only during the main but also during the initial phase of the magnetic storm. If the *IP* is short and not clearly expressed other types of oscillations and mixed regimen may be present. As a result of the fact that *pc* are frequently observed during the *IP*, and from the similarity of the oscillations composing the fine structure of *SSC* with *pc* we can suggest the same nature of these oscillations.

* The investigations of *SSC* in the greater period range show that short period osscillations are superimposed on more slow changes.

The Main Phase (*MP*) of Magnetic Storms

The main phase of the magnetic storms due to the adopted conceptions is the period when occur the injections of plasma through the border of C-F cavity, begins the trapping of charged particles, and commence the formation of the ring current as well as the injections of separate imbedded in the stream irregulaties into the polar regions. What can be said about the fine structure of the main phase of the storm and what is the difference in this respect between the main and initial phases?

The important features of the main phase are:

a) A great number of bursts which are followed by changes in the oscillatory regimen and frequent changes of the amplitudes of oscillations. These bursts can have a world-wide or more local character (that is they can be observed for instance only in the polar caps or auroral zone or simultaneously in all investigated longitudinal interval and the high latitudes).

b) Development in the centre of the main phase of oscillations diminishing on periods (*IPDP*) or "Solar whistles" in the terminology of western hemisphere.

c) Excitation as a rule of short irregular oscillations (*sip*) and *PP* and their frequent interchange (that is oscillations correlated as was noticed before with corpuscular injections of different types).

Bursts of Oscillations

The first results of investigations of fine structure of macroscopic magnetic disturbances suggest that probably the injections continue not as long as the macroscopic disturbance continues but as long as its fine structure is observed. Perhaps it may be due to the fact, that the macroscopic disturbance is formed both during the injection and during the processes in the Earth's atmosphere which continue after the injection is finished.

The bursts of oscillation and their duration characterize from our point of view the injections of irregularities imbedded in the stream. It seems therefore that the investigation of such bursts is one of the more perspective methods of the corpuscular stream structure analysis. The results obtained up to date show, that the dimensions of such irregularities in the stream may be quite different. For instance storms with frequent relatively short (1 hour and less) irregularities are — 24/X-58; 25/II-59; 4/XII-58. On the other side there are storms with bursts (and therefore irregularities) which continue many hours (22-24/VIII-58, 2-3/IX-57; 6-7/VI-58). The structure of corpuscular streams which excited these storms was probably more homogeneous than in the former case. The greatest duration of oscillations after the burst is approximately 10 hours. Bursts continuing 4 hours or less are frequent. Most frequent are bursts continuing less than 1 hour.

Intervals of Pulsations Diminishing on Periods (*IPDP*)

The *IPDP* or solar whistles are described in (17, 18). This phenomenon consists of the intensive burst of irregular oscillations after which develops a series of regular oscillations of *PP* type with periods diminishing from 10 sec to fractions of a second. The develop-

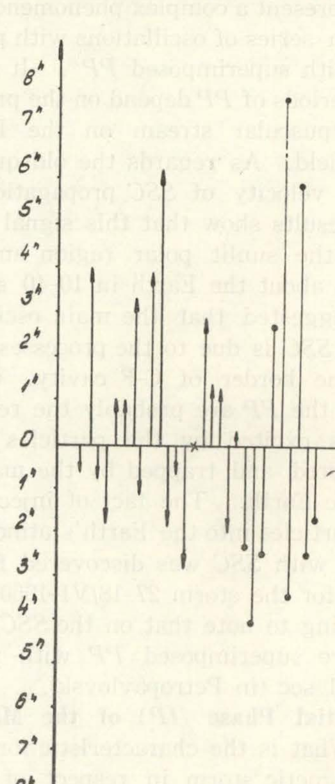

Fig. 5. Distribution of *IPDP* and *WWB* around *H*min in *Dst*-variation
↑ - *WWB* ↑-*IPDP*

ment of oscillations of different periods and the sequence of their changing can differ from case to case.* The connection of this phenomenon with aurorae in low latitudes, X-ray bursts and the disturbances in the ionosphere was desdribed in (17, 18). The study of this phenomenon in respect of *Dst* variation showed the following.

The *IPDP* are always registered in the main phase of the storm. From 28 analysed cases of *IPDP* (Fig. 5) 20 were registered in the average not farther, than 1.5 hours from the moment of the greatest depression of *H* in the course of *Dst* variation. It is interesting to note, that the *IPDP* are distributed symmetrically relative to *H* minimum (that is they lie mostly in the intervals 1-2 hours before and after *H* min.). An important feature characteristic for *IPDP* or for world wide bursts is the coincidence of their excitation with the development in low and middle latitudes of characteristic microbays or pikes. These microbays belong probably to the sinphase type of disturbance described in (27). The regularities of the simultaneous occurrence of *IPDP* and these positive microbays or bays were investigated for 23 cases of *IPDP* and world wide bursts (*WWB*) (Fig. 6). 20 of these cases fell on the beginning of the bay (with precision 10 min). The development of *IPDP* starts as a rule after the development of the bay has already begun. It follows from this fact that the *IPDP* or *WWB* are in some respect similar to the phenomena occurring simultaneously with *SSC*. In both cases they develop in middle latitudes in conditions of *H*-rising. The further sequence of events is however quite different.

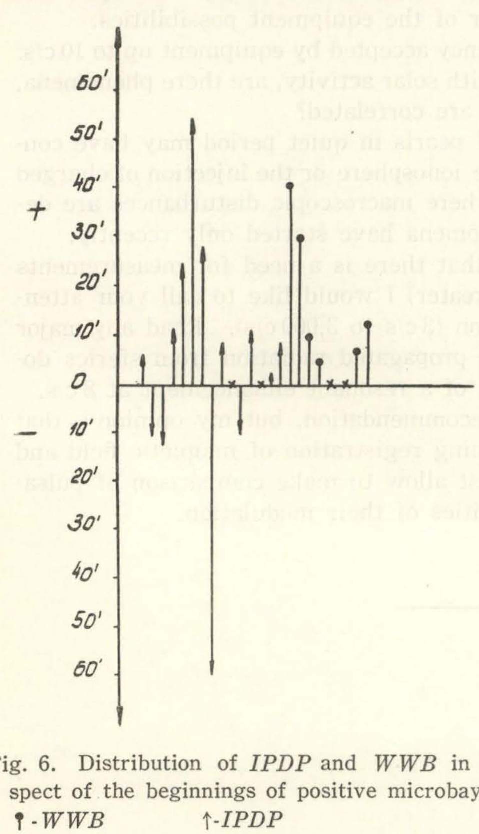

Fig. 6. Distribution of *IPDP* and *WWB* in respect of the beginnings of positive microbays.
↑ - *WWB* ↑ - *IPDP*

* It was stressed by Campbell and others, that series of oscillations with rising periods may occur also. Our experience shows that such cases occur but less frequent than *IPDP*.

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Discussion

Sir Charles Wright: 1. What is the highest frequency observed during magnetic storms?

2. Did I understand Dr. Troitskaya to say that equipment should be designed to accept higher frequencies? Our recent experience suggests this might be helpful in examining the origin of *pt* impulsive records.

Troitskaya, V. A.: 1. The highest frequency we have observed is of the order of 3-4 cycles. Our equipment is not designed to fix pulsations of higher frequences. These values are already on the extreme border of the equipment possibilities.

2. There are advantages in increasing frequency accepted by equipment up to 10 c/s.

Dungey, J. W.: If pearls are anticorrelated with solar activity, are there phenomena, other than magnetic storms, with which pearls are correlated?

Troiskaya, V. A.: The excitation of series of pearls in quiet period may have connection with the changes of conductivity in the ionosphere or the injection of charged particles, with density less than in the cases where macroscopic disturbances are developed. The correlation studies of these phenomena have started only recently.

Campbell, W. H.: With regard to your note that there is a need for measurements at frequencies higher than 3 c/s (to 20 c/s or greater) I would like to call your attention to a wealth of observations in the ELF region (3 c/s to 3,000 c/s). Read any major journal concerning this work. The zero mode propagated radiation from sferics dominates this entire region with some indication of a resonant enhancement at 8 c/s.

Troitskaya, V. A.: This is a very valuable recommendation, but my opinion is that supplementary to this data, special 24 hour running registration of magnetic field and earth currents has to be organized, which must allow to make comparison of pulsations on great territories, to study the peculiarities of their modulation.