# Magnetic and optical measurements and signatures of reconnection in the cusp and vicinity 

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#### Abstract

The study of geophysical processes in the cusp and its nearby magnetospheric regions - the mantle and the low-latitude boundary layer - is a crucial link in the chain of understanding the mechanism of the solar-terrestrial relationship. The magnetic conjugation of these regions with the high-latitude ionosphere permits the study of the solar wind-dayside magnetopause interaction via ground-observed ionospheric phenomena. The major topics covered are the dayside aurora in Spitsbergen and the Alfvén waves detected by an induction magnetometer as high-latitude geomagnetic Pc1 pulsations. The results presented establish a relation between the aurora and pulsation dynamics and the reconnection phenomenon which occurs at negative IMF $B_{\mathrm{z}}$ values and which is commonly accepted to be the most likely way for solar wind energy to penetrate into the inner magnetosphere. The results also suggest that the Spitsbergen optical and magnetic measurements provide an opportunity for the world scientific community to


[^0]solve the major space weather problem of monitoring the replenishment of the energy expended in the course of magnetospheric substorms.

Keywords: cusp, reconnection, dayside auroras, pulsation Pc1

## 1. Introduction

The key link in the formation of cosmic weather is the solar wind energy transfer to the inner magnetosphere. Energy accumulation in the magnetosphere tail can stimulate the generation of magnetospheric substorms and promote their recurrence. Theorists believe that the dominant means of energy transfer through the magnetopause is the reconnection of the magnetopause-forming geomagnetic field lines and the interplanetary magnetic field (IMF) lines, when the $B_{z}$ component of IMF is negative (further - the South IMF). The reconnected field tubes are pulled away by the solar wind from the cusp through the polar cap to the night side and 'pile up' in portions of the magnetosphere tail, which leads to magnetic energy heightening in the night magnetosphere. The explosive release of this energy generates a magnetospheric substorm.

The geomagnetic field lines forming the magnetopause penetrate the ionosphere near cusps (approximately at $78^{\circ}$ of geomagnetic latitude in the Northern hemisphere), thus providing a peculiar 'projection' of the processes proceeding on the magnetopause onto the dayside ionosphere of the arctic latitudes. 'Projection' is realized by charged particle and Alfvén wave propagation along the field lines, so that the auroras and geomagnetic pulsations observed in the vicinity of the cusp may be used for studying the reconnection mechanism.

The observation of auroras as a research instrument is more advantageous than other types of observations, because
optical methods can be exploited to examine the structure and dynamics of the phenomenon in a large ionospheric region. The main shortcoming of optical observations lies in their dependence on the level of illumination and on weather conditions. Possibly for this reason, the 'practical' question of solar-terrestrial connection, namely, the question of what particular solar wind-magnetopause interaction process is reflected in dayside auroras has been poorly investigated.

The growing arsenal of observational means allows drawing on the results of other types of measurements (magnetic, radar, and satellite-based) for optical studies in the dayside sector of the high-latitude ionosphere. In particular, statistics show [1] that in day hours, the Spitsbergen archipelago 'passes' under the cusp and the projection of the adjacent magnetospheric formations - the mantle and the plasma low-latitude boundary layer (LLBL). The first question arising in the attempt to relate dayside auroras to processes in the magnetopause is in which magnetospheric domain their source lies. If auroras occur in the region of precipitations typical of the cusp or the mantle and drift towards the pole, then one can assert with high probability that their source lies on the newly reconnected field lines drifting towards the magnetosphere tail.

Analysis of the literature shows that regions of the cusp and its neighborhoods exhibit no direct correlation between auroras and precipitation areas; in near-midday hours, the detection of a weak glow is technically difficult, since the horizon is illuminated by the Sun, and because of frequent cloudiness the intervals accessible for observations are not numerous, even in the darkest season. Analyses of individual events [2-4] point to the possible relation of near-midday auroras and precipitations from these magnetosphere domains, but no reliable statistics have been obtained yet.

As distinct from aurora detection, Pcl pulsation detection is not impeded by weather conditions, and the time series of continuous observations of such pulsations in Barentsburg (Spitsbergen archipelago) is over 15 years. However, in searching for the Pcl source, one should bear in mind that waves of this frequency range generated in the magnetosphere can propagate from the place of their fall into the ionosphere through an ionospheric waveguide. To exclude from consideration waves whose source is not located near the magnetopause but in the depths of the magnetosphere, the data from an induction magnetometer in Barentsburg were analyzed together with the data from magnetometers in Scandinavia and on the Kola Peninsula.

The present paper is aimed at demonstrating through particular examples the capability of the measurement facility of Polar Geophysical Institute (PGI) in Spitsbergen to register optical and magnetic phenomena with sources located on open field lines, i.e., in the cusp or the mantle. The positions of cusp and mantle boundaries in the ionosphere were determined by the character of precipitating particles by DMSP (Defence Meteorological Satellite Program) satellites flying above the observation region. The character of ionospheric convection in the course of the investigated events indicates that the source is driven to the magnetosphere tail, which gave grounds to associate the observed phenomenon with reconnection.

## 2. Instrumentations and methods

We use here the data from aurora recording at the Barentsburg PGI geophysical observatory (denoted further as

BAB) in the Spitsbergen archipelago by a digital 'all-sky' camera on a CCD (charge coupled device) matrix $540 \times 540$ pixels in size which was used to monitor auroral activity in November 2012. The auroras were detected in white light (WL) with a time resolution of 1 shot a second. To establish the auroral intrusion boundaries by the DMSP satellite data, the automatic algorithm proposed in Ref. [5] and realized for online work on the site http://sd-www.jhuapl.edu/Aurora/ dataset_list.html was applied.

An important link in the joint analysis of data is the correct alignment of auroras to the regions of satellite measurements. This is done by projecting the satellite trajectory to the altitude of the lower edge of the auroras with an indication of the domain boundaries. An exact binding of auroras to geographical coordinates was done with reference to stars using the program package worked out for the Swedish project Auroral Large Imaging System (ALIS) (http://www.irf.se/~urban/ $\mathrm{avh} / \mathrm{html} / \mathrm{htmlthesis} . \mathrm{html}$ ). To 'project' the satellite position to the aurora altitude, we applied the IGRF (International Geomagnetic Reference Field) model of a geomagnetic field. To determine the height of the spherical surface on which the satellite trajectory coincides with the position of the auroras, we estimated the altitude of the lower aurora edge relying on the calculations of the altitude profile of luminosity according to data on precipitating particles [6].

Alfvén type waves are related to ion-cyclotron waves, which are registered on Earth's surface as geomagnetic field variations in the Hertz range ( Pcl pulsations). In the BAB observatory, Pcl pulsations are detected by an induction magnetometer operating at the sample rate of 40 Hz . For a visual representation of wave activity, dynamical spectra (sonograms) were constructed in the investigated range, which reflected the two-dimensional distribution of signal intensity in frequency-time coordinates. To exclude from consideration those waves whose source is not located near the magnetopause but is projected to the auroral or midlatitude ionosphere, the data of the induction magnetometer in BAB were analyzed together with magnetometer data in Scandinavia (the Kilpisjarvi observatory - KIL) and on the Kola Peninsula (Lovozero observatory - LOZ).

The optical and magnetic measurements in BAB were supplemented with data from the radars EISCAT (European Incoherent Scatter Scientific Association) and SuperDARN (Super Dual Auroral Radar Network) on ionospheric convection, whose character is largely determined by the IMF. This complex approach to the analysis of the phenomenon allows diminishing the ambiguity about its interpretation [2], but then the number of events accessible for analysis turns out to be limited. Nevertheless, the results of the complex analysis of individual events may underlie further research. In Sections 3 and 4, we give several examples demonstrating the ability of optical and magnetic observations in Spitsbergen to investigate the processes on the magnetopause in application to cosmic weather problems.

## 3. Analysis of two flights of DMSP satellites within the camera field of vision in Barentsburg

### 3.1 Aurora response <br> to interplanetary magnetic field variations

Figure 1 presents keograms characterizing aurora dynamics along the geomagnetic meridian on which a camera is


Figure 1. Response of auroras to variations of the interplanetary magnetic field. The vertical straight lines show the instants of satellite flights in the camera field of vision in Barentsburg, and the white arrow indicates the beginning of the equatorial auroral shift in the event of 24.11.2012. UT is a universal time.
installed, and also the variations of $B_{z}$ and $B_{y}$ components of the IMF in heliocentric solar-magnetic (Geliocentric Solar Magnetospheric, GSM) coordinates at the head point of a shock front. The situation in the interplanetary medium is characterized by the rise of the curve $B_{z}$ in the direction of positive values at the beginning of the intervals. In the middle of the intervals, $B_{z}$ begins to turn back towards high negative values, after which the $B_{z}$ component remains stably negative for some time in both the events considered. The negative $B_{z}$ component must theoretically shift the cusp southwards from its statistical position, and the cusp will find itself in the field of vision of the camera in BAB. Simultaneously with $B_{z}$, the $B_{y}$ component begins to decrease, and during the flights of DMSP satellites F16 and F17 over Barentsburg (see the vertical lines in Fig. 1) the $B_{y}$ component takes values close to zero. Together with the high negative $B_{z}$ values, this means the following: the IMF lines are collinear and opposite in direction to the geomagnetic field lines that form a nearmidday magnetopause region, which theoretically favors reconnection.

In both events, the auroral activity has a form typical of dayside auroras displacing towards the pole (Poleward Moving Auroral Forms, PMAFs). In the event on

17 December 2012, the southward $B_{z}$ turn is accompanied by a clear shift of PMAF as a whole in the direction of the equator. The shift begins 10 min after $B_{z}$ changes sign from plus to minus. In the event on 24 November 2012, the starting point of the aurora response to a $B_{z}$ movement towards high negative values is not very pronounced, which can be caused by the absence in the prehistory of a long interval of aurora shifts to the pole against the background of positive $B_{z}$ values. According to the OMNI (Offender Management Network Information system) web-resource, the head point of the shock wave was, in this case, located two Earth radii closer to Earth than in the case considered above, and therefore the delay time of aurora's reaction to $B_{z}$ will be less than that in the event on 17 December. Judging by the aurora dynamics presented in Fig. 1b, one may believe that their shift towards the equator began at about 07:12 UT (this moment is marked by the white arrow in the keogram).

The occurrence and subsequent poleward drift of a single arc 10 to 15 min after the beginning of PMAF drift to the equator are common to both events. Not long before the occurrence of a single arc and several minutes after its disappearance, DMSP satellites flew through the camera field of vision (the vertical lines in Fig. 1). The spectrograms demonstrating the character of precipitations over Barentsburg are displayed in Fig. 2. One can see that, before the appearance of a single arc, in both cases the F17 satellite registered precipitations typical of the cusp. After the arc disappeared, according to F16 data the interface between the mantle and the low-latitude boundary layer (LLBL) was projected in the field of vision of the camera. A detailed joint analysis of the optical and satellite-based data is presented in the section that follows.

### 3.2 Rayed structures in the cusp region and their related precipitations

To compare the satellite-based and optical data, it is necessary to determine the altitude of auroras to which the satellite trajectory with marked magnetospheric domain boundaries will be further projected. This is normally done proceeding from a priori information, but in this case the satellite data made it possible to calculate the altitude luminosity profiles by the method applied in paper [6] and to use them for estimating the luminosity altitude at the time of satellite conjunction with the luminous region.

The data gathered by F17 in Fig. 2 show that in the event of 17.12.2012 the satellite was flying from 07:32:38 to 07:32:45 UT through precipitations typical of the cusp and immediately before crossing the boundary with LLBL detected a burst of electron precipitations. The lower edge of the aurora due to this burst was located at an altitude of 240 km . The result of matching the optical data to the projection of the satellite to this altitude is demonstrated in Fig. 3a. The solid line stands for the projection of the trajectory fragment on which the satellite registered the cusp precipitations. One can see that when the precipitations happened the satellite (the white circle in the trajectory) was conjugated with a weak rayed structure.

During the flight of satellite F17 in the event on 24 November 2012, the $B_{z}$ value was almost twice as large as that on 17 December, which resulted in a considerably larger shift from the zenith of the equatorial cusp edge, together with auroras. In a joint analysis of the optical and satellite data, we therefore encountered the difficulty of reliable identification


Figure 2. Distribution of the magnitude of the differential energy flux of the precipitating particles $F_{E}\left[\mathrm{eV}\left(\mathrm{eV} \mathrm{cm}^{2} \mathrm{~s} \mathrm{sr}\right)^{-1}\right]$ along the satellite trajectories during their flight over the region of optical observations (according to the data on the site http://sd-www.jhuapl.edu/Aurora/spectrogram/index.html). CPS is the central plasma sheet, BPS is the boundary plasma sheet, LAT and LON are, respectively, the geographical latitude and longitude of the subsatellite point (satellite projections onto Earth's surface), MLAT is the magnetic latitude of the subsatellite point, MLT is magnetic local time, and JHU/APL is Johns Hopkins University (JHU) Applied Physics Laboratory (APL).
of the lower edge of weak auroras in the cusp against the background of intense rayed structures extended in altitude. This especially concerns the reproduction of auroras on paper media. The spectrogram in Fig. 2c shows that the satellite was flying through the cusp from 07:26:27 to 07:26:51 UT and, immediately after crossing the boundary with the mantle, i.e., at the pole boundary of the cusp, detected intense electron precipitations. The altitude of 255 km is determined as the lower edge of the aurora. The result of matching the optical data to the satellite projection onto this altitude is shown in Fig. 3b. The white line gives the portion of the trajectory in the region of cusp precipitations. One can see that the satellite is projected to the region 'shadowed' by the glow of one of the rays of the bright auroral form at the southwest edge of the camera field of vision.

An interesting feature of the precipitations associated with rayed structures in the cusp is the fact that, along with the electron precipitations, the flow of precipitating ions does not get weaker (Fig. 2a, c). A virtually complete ion 'locking' over the arcs was observed earlier [2]. This was explained by the presence above the arcs of the region of the accelerating potential, i.e., a double layer or an 'anomalous' resistance region. What has been said above suggests that the auroras observed in the cusp should be due to scattered rather than accelerated electrons.

In Section 3.3 we analyze the behavior of auroras, common to both events, after the flight of the F17 satellite through the cusp, namely, strengthening, poleward shift, and disappearance of the rayed arc. Special attention in the analysis is then paid to determining the rayed arc position relative to the magnetosphere domain boundaries.

### 3.3 Hypothetical position of rayed structures <br> at the end of the drift

As can be seen in Fig. 1, the aurora dynamics immediately after the flight of the F17 satellite through the cusp developed similarly in both cases, namely, the single arc strengthened to the south of the zenith and then drifted toward the pole and faded. The beginning of the structure drift was preceded by the interval of a practically unchanged IMF, and so the position of ionospheric projections of magnetosphere domains found from the data of previous F17 flights could not have changed so drastically that the motion of the structure towards the pole might be associated with the poleward shift of the domain boundaries.

Owing to a favorable concourse of circumstances, the F16 satellite flew through the region of optical observations soon after the F17 satellite. The situation with precipitations at the time of the F16 flight differs from the one that took place ten minutes earlier during the F17 flight. The cusp precipitations were absent and the boundary between closed and open field lines that we define as the pole boundary of LLBL in the event of 17.12.2012, and as the equatorial boundary of the mantle in the event of 24.11 .2012 , shifted towards the pole. Hence, to estimate the position of the rayed structures at the end of their drift, we will take advantage of the data from the F16 satellite that give the position of precipitation boundaries $\approx 2 \mathrm{~min}$ after the trail of the structures could no longer be identified on keograms.

Results of the alignment of arcs and the domain boundaries are presented in Fig. 4. Because of aurora weakness immediately before their disappearance, the frames refer to the instant of time when the structure was


Figure 3. Original photos ( $\mathrm{a}, \mathrm{b}$ ) taken by the G550 camera and their corresponding projections ( $\mathrm{c}, \mathrm{d}$ ) onto the plane together with a part of the trajectory of the DMSP F17 satellite in the cusp. The white circle shows the satellite position at the instant of detection of precipitating particle flux strengthening.
still drifting, i.e., 3.5 min prior to the instant when the F16 satellite left the mantle precipitation region. The form of the drifting structure is identified more clearly in the event of 24.11.2012. To make the identification of the very weak arc in the event of 17.12.2012 easier, when combining the optical and satellite data, we had to resort to artificial accentuation ('dyeing') of four of its rays (Fig. 4b). The dashed line with the arrow in Fig. 4 points to parts of the F16 trajectory projected together with the auroras onto a plane whose altitude is assumed to be equal to 250 km (the lower edge of the aurora). Recall that in the photos taken by an 'all-sky' type objective the lower edge of the aurora in natural conditions corresponds to the far edge (from the frame center) of the luminescent region in the frame. The satellite position at the instant of time the equatorial boundary of the mantle is crossed is shown by the white circle. The white solid line passing through the satellite and oriented approximately along the geomagnetic latitude (parallel to the arcs) marks the assumed position of the boundary between closed and open field lines. Considering that the photos were taken 3.5 min before the satellite crossed the equatorial boundary of the mantle and the arc was moving towards the pole within
these 3.5 min , it may be assumed that in both events the source of the drifting auroras was located in the open field lines. In Section 3.4, we shall discuss possible versions of the interpretation of the result obtained.

### 3.4 Generalization of the results of optical observations

We have analyzed two cases of aurora observations in the vicinity of the dayside cusp together with the data of DMSP satellites F17 and F16 that flew one after another through the camera field of vision in Barentsburg with an interval of about 10 min . Keograms show that the auroral activity in both events developed by analogous scenarios, because the character of IMF variation was also similar. The movement of the $B_{z}$ component towards negative values was accompanied by a reconstruction of the dayside part of the magnetosphere, as a result of which the cusp appeared to be in the zenith of the Barentsburg observatory.

We have shown that the weak bursts of electron precipitation registered by the satellite inside the cusp precipitation correspond to the weak 'red' rayed structures which were located near the pole and equatorial cusp boundaries and were generated by scattered rather than accelerated electrons.


Figure 4. Drifting arc position relative to the boundary between closed and open field lines by DMSP data from F16 on 24 November 2012 (a) and 17 December 2012 (b). The dashed line is a part of the trajectory, the solid line is the geomagnetic latitude where the boundary passes between the mantle and the low-latitude boundary layer; the weak arc rays in Fig. b are accented by white lines.

Another element of similarity of auroral activity is a notable poleward shift of the rayed arc which began almost immediately after the flight of the first satellite (F17) and ended several minutes before the flight of the second one (F16). According to the data from F16, the source of the drifting arcs is located in the region of open field lines, for which reason the reconnection of IMF lines of force with geomagnetic lines of force is assumed to be the most probable mechanism of the observed phenomenon. According to the data from the F16 satellite, the character of ionic precipitations (Fig. 2b, d) testifies in favor of this hypothesis. The precipitations have a pronounced dispersive form when the particle energy increases with satellite motion from high to lower latitudes, which is traditionally associated with a satellite's crossing the tubes drifting in the antisolar direction.

Of particular interest are the dispersion structures observed in the intervals of 07:44:05 to 07:44:35 UT (17 December 2012) and 07:35:55 to 07:36:26 UT (24 November 2012). The structures cross the mantle/LLBL boundary, and in view of what has been said above they can be associated with the field tubes penetrating the mantle from the low-latitude boundary plasma sheet.

## 4. High-latitude geomagnetic Pc1 pulsations as a signature of reconnection

Pc1-range ( $0.1-2 \mathrm{~Hz}$ ) geomagnetic pulsations are customarily associated with Alfvén type waves generated due to the development of ion-cyclotron instability of anisotropic plasma. Their main peculiarity is 'attachment' to the geomagnetic field lines, which essentially permits an observer on Earth to find the position of the source of pulsations in the magnetosphere (under the condition that the detected pulsations have not come to the observer through an ionospheric waveguide).

From the point of view of the formulated problem, highlatitude Pc 1 pulsations are of a particular interest. For example, the authors of paper [7] proposed the use of highlatitude Pcl pulsations for finding the cusp position. In the interplanetary medium, emissions in this range are observed in the part of the transition region known as the magnetic barrier [8]. According to paper [9], it theoretically possible for pulsations to move from the transition layer to the magnetosphere. In the course of reconnection, the anisotropic plasma from the magnetic barrier can appear in the geomagnetic field lines connected with the ionosphere in the cusp region, and the ion-cyclotron waves propagating along the field lines can be detected on Earth's surface in the form of Pcl pulsations.

If reconnection takes place under negative $B_{z}$ conditions, the source of pulsations remains in open field lines carried away by a solar wind stream to the magnetosphere tail. To register these pulsations, a magnetometer must be located in the polar cap. According to statistics [1], the cusp is typically projected closer to the pole relative to Spitsbergen. When the $B_{z}$ component of IMF is negative and large in absolute value, the cusp shifts towards the equator (an example of an extreme case is given in Fig. 1b) and Spitsbergen appears to be inside the polar cap in the region of open field lines. Continental magnetometers can still remain in closed field lines. Several such situations were analyzed in paper [10]. Below, we shall briefly review the results of this paper.

### 4.1 Midday Pc1 in the polar cap.

## Description of an individual event

The event chosen for demonstration occurred during the main phase of a moderate magnetic storm which was caused by Earth passing through a magnetic cloud characterized, in particular, by high negative values of the IMF $B_{z}$ component. The geomagnetic field variations in the frequency range of 0 to 40 Hz were measured in three observatories: Barentsburg (Spitsbergen archipelago), Kilpisjarvi (the north of Finland), and Lovozero (the center of the Kola Peninsula). Within the time of the event under consideration, two DMSP series satellites flew over the region of magnetic measurements almost simultaneously (Fig. 5a). The data from the satellites showed that, because of the large negative $B_{z}$ component $(-10 \mathrm{nT})$, the cusp had shifted by approximately $10^{\circ}$ southward relative to its statistical position. As a result, the BAB observatory found itself at the foot of open field lines, in the region of the polar cap, while the KIL position can be identified with the position of the cusp or a part of LLBL east of the cusp. The LOZ observatory was located inside the projection of LLBL or the boundary plasma sheet (BPS).

The time evolution of geomagnetic activity in the ultra-low-frequency (ULF) range is demonstrated in Fig. 5b-d in sonograms. One can see that Pcl pulsations were observed at BAB only (Fig. 5b), which at that time resided in the polar


Figure 5. Positions of BAB, KIL, and LOZ observatories relative to the magnetospheric domain boundaries according to the data from DMSP satellites F12 and F15; PRN is polar rain, Uncl. (unclassified) means that the online recognition program failed to assign, using particle characteristics, the precipitation source to a certain magnetospheric domain. (b-d) The form of ULF activity at these observatories.
cap. At the KIL (Fig. 5c) and LOZ (Fig. 5d) stations located at the foot of closed field lines, pulsations were absent. We believe that such spatial distribution of Pcl pulsations implies that the emissions in BAB were not a result of simple signal propagation in an ionospheric waveguide. Consequently, the source of Pcl pulsations was situated on open field lines.

Data from the Wind satellite show that before the beginning of pulsations in Barentsburg the $B_{y}$ component decreased almost to zero. That is, before the beginning of Pcl pulsations, the region of reconnection on the magnetopause shifted in the direction of the midday meridian, where the $y$-component of the Earth field is also insignificant and the conditions (opposite directions of the fields) are the most favorable for reconnection.

The ionospheric conditions over Spitsbergen were monitored by the SuperDARN radar system. The diagrams in Fig. 6 demonstrate the main peculiarities of the behavior of large-scale convection within the considered time interval, including the Pcl activity time interval. Before the beginning of pulsations, the convection over Spitsbergen had an azimuthal direction (along the latitude), and so the observatory was in the path of magnetic field tubes drifting from the magnetosphere tail (Fig. 6a, d). The appearance of pulsations coincides in time with the change in the character of convection. Figure 6b, e indicates that the drift over Spitsbergen took the meridional direction. The dashed line gives the trajectory of the DMSP F12 satellite at an altitude of 300 km . The white circle in Fig. 6b stands for the cusp position. The plasma stream along the meridian may imply that BAB now resides in the path of the newly reconnected magnetic field tubes. This means that Pcl activity in the polar cap may have resulted from the penetration of anisotropic plasma into the magnetosphere from the transition region (more precisely, from the magnetic barrier). The diagrams in Fig. 6c,f correspond to the instant of pulsation termination. One can
see that convection over BAB has again acquired the azimuthal direction.

### 4.2 Midday Pc1 in the polar cap.

## Statistics and scenario of the phenomenon

We looked through the data gathered by the Wind satellite from October 2001 to October 2002 and selected those cases when the $B_{z}$ component of IMF assumed high negative values near a local midday in BAB.

The analysis of all the events revealed the following basic regularities (the results are presented in more detail in paper [10]).

- For all the cases, the data of DMSP satellites show that the BAB magnetometer was located in the polar cap, while the other two magnetometers (KIL and LOZ) were in the region of closed field lines.
- KIL and LOZ exhibited pulsations in none of the cases.
- During the $10-\mathrm{min}$ interval that included the moment of pulsation observation, the $B_{y}$ component of IMF diminished almost to zero.
- In three cases, the data from the SuperDARN radar were accessible, which showed that before the beginning of Pcl pulsations the direction of convection over Spitsbergen changed to antisolar.
- About 10 min before the beginning of Pcl, the IMAGE (International Monitor for Auroral Geomagnetic Field) magnetometer network exhibited pulsations of the Pc5 range with increasing amplitude. The intensity of pulsations was higher at the boundary between closed and open field lines. No pulsations were observed in the direction from the boundary to the pole.

Thus, in the considered seven cases of Pcl pulsations observed at high latitudes in day hours in the periods of high negative values of the IMF $B_{z}$ components, the high-latitude


Figure 6. (Color online.) Character of ionospheric convection over Spitsbergen before ( $\mathrm{a}, \mathrm{d}$ ), in the course of ( $\mathrm{b}, \mathrm{e}$ ), and after ( $\mathrm{c}, \mathrm{f}$ ) the interval of pulsations in Barentsburg by SuperDARN measurements (a-c) and reconstruction of this convection by SuperDARN data with allowance for IMF (d-f). The dashed line is the DMSP satellite trajectory, the white circle on the trajectory is the cusp position, and the black circle is the Barentsburg observatory. The arrows show the direction of convection rate, and $\Lambda$ is geographic latitude.
observatory (BAB) was at that time in the polar cap, while the auroral zone observatories (KIL and LOZ) remained in the region of closed field lines. Pulsations were detected in the polar cap only. (A similar result had been reported before in papers [11, 12]). This could be caused by a very strong decrease in the Pcl amplitude with increasing distance (about 10 dB each 100 km according to Ref. [11]). Taking into consideration the possibility of such weakening of pulsations, the authors of paper [12] concluded that the observed Pcl must be generated in a spatially limited region. Thus, the absence of pulsations to the south of BAB may mean that pulsations could not have come from low latitudes along the ionospheric waveguide, and their source must be located on open field lines and must have limited spatial dimensions.

The opinion that anisotropic proton plasma may be the source of Pc 1 is widespread. Since parts of the magnetosphere
tail are generally characterized by a low plasma content, the question arises as to where it appeared from in the cases considered. We believe that the anisotropic plasma has been 'brought in' from the transition region (the solar wind region immediately before the dayside magnetopause) by newly reconnected field lines drifting through the polar cap from the cusp towards the night side. The specific IMF effect on the Pc 1 regime in the BAB data, namely, their relation with the decrease in the $B_{y}$ component of IMF, confirms this hypothesis.

## 5. Conclusion

The energy and matter transfers through the dayside magnetosphere are reflected in various ionospheric perturbations observed over Spitsbergen in day hours. Therefore, the observational facility located here involves optical magneto-
metric equipment and can efficiently be used to study a whole number of important questions about cosmic weather. In this paper, we demonstrate, using concrete examples, the possibility of using optical and magnetic phenomena for diagnostics of reconnection.

We emphasize the importance of a precisely complex ('multi-instrumental') approach to the analysis of daytime ionospheric perturbations and the necessity in this connection of a more thorough comparison of different measurements in space. In the case of auroras, this is the binding of auroras on stars allowing error minimization in finding the aurora position with respect to the magnetosphere domain boundaries. In the case of Pc 1 pulsations, this is exclusion of situations of pulsation propagation in the region of observations along the ionospheric waveguide.

An important supplement to the optical and magnetic data are the results obtained by DMSP satellites on precipitating particles, which make it possible to determine the position of cusp boundaries in the ionosphere and, therefore, the position of the boundary between closed and open geomagnetic field lines, as well as radar data concerning the character of ionospheric convection in the observational regions. The 'monoinstrumental' approach may lead to misinterpretation of the observed phenomena (see paper [2]).

## Acknowledgments

The authors are grateful to research workers at PGI whose professional activity promoted the development of Barentsburg observatory and obtaining high-quality data, and to N N Safargaleeva (PGI) for her help in selecting intervals of optical observations. The authors thank P T Newell (Johns Hopkins University, APL US) for preparing and distributing on the Internet the observational data from satellites of the DMSP series. The particle detectors for DMSP satellites were designed by D Hardy (Air Force Research Laboratory). The program package for aurora binding on stars was prepared by B Gustavsson (Swedish Institute of Space Physics) in the framework of the ALIS project. The data on the interplanetary magnetic field were obtained through the OMNI CDA Web data array.

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    Received 14 April 2015
    Uspekhi Fizicheskikh Nauk 185 (6) 655-663 (2015)
    DOI: 10.3367/UFNr.0185.201506j.0655
    Translated by M V Tsaplina; edited by A Radzig

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