STUDY OF THE SUBSTORMS OBSERVED OVER APATITY IN 2015/2016 SEASON

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Abstract: *In this work the substorms, registered during the 2015/2016 observational season over Apatity, are examined. Observations of the Multiscale Aurora Imaging Network (MAIN) in Apatity have been used. Solar wind and interplanetary magnetic field parameters were taken from the 1-min sampled OMNI data base. Substorm onset was specified and the further substorm development was followed by the 10-s sampled data of IMAGE magnetometers data set and by images and keograms of the all-sky and GC cameras in Apatity. Subject of the study were the characteristics of substorms originated during different geomagnetic conditions. The behaviour of the substorms developed during geomagnetic storms and in non-storm time was discussed.*

ИЗСЛЕДВАНЕ НА СУББУРИТЕ, НАБЛЮДАВАНИ НАД АПАТИТИ ПРЕЗ СЕЗОНА 2015/2016

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Резюме: *В тази работа са представени суббурите, регистрирани от Апатити през наблюдателния сезон 2015/2016 г. Използвани са наблюдения на системата камери Multiscale Aurora Imaging Network (MAIN) в Апатити. Ппараметрите на слънчевия вятър и междупланетното магнитно поле със стъпка 1 мин. са взети от базата данни OMNI. Началото на суббурите беше уточнено и беше проследено по-нататъшното им развитие по магнитните данни със стъпка 10 сек. от мрежата магнитометри IMAGE и по изображения и кеограми от all-sky и GC камерите в Апатити. Обект на изследването са характеристиките на суббурите, възникнали при различни геомагнитни условия. Дискутирано е поведението на суббурите, развили се по време на геомагнитни бури и при небуреви условия.*

Introduction

Substorms are a picturesque phenomenon that interested people for centuries. With the development of the science auroral substorms and their relation with other processes were studied. Akasofu reviewed these phenomena [1, 2, 3]. The sudden brightening, the bulge formation and its expansion in all directions, mostly to the North, are the final event of a sequence of phenomena, the manifestation of the magnetospheric substorm. The magnetospheric substorm is a disturbance of the magnetosphere brought by the solar wind transfer of magnetic flux from the dayside to the magnetospheric tail lobes and its return through the plasma sheet. It is known that the auroral substorm development differs depending on the conditions in the solar wind [e.g. 4, 5]. To be more specific, the solar wind parameters influence the substorm intensity, the substorm onset location, the substorm extent, the occurrence of substorms at high geomagnetic latitudes [e.g. 6, 7, 8, 9, 10].

Besides, disturbances in the solar wind, especially magnetic clouds (MC) and the regions in front of the flows in the solar wind (CIR and Sheath) can often provoke geomagnetic storms differing by their intensity and other parameters [11, 12, 13, 14]. Therefore, substorms could be observed under different interplanetary conditions: during the passage of different solar wind streams and structures by the Earth, during the development of different geomagnetic storms, as well as in quiet conditions.

The goal of this work is to identify, classify and examine the substorms during different phases of geomagnetic storms and in non-storm conditions using measurements of the camera system MAIN in Apatity during 2015/2016 observational winter season.

Instrumentation and data used

Measurements from the Multiscale Aurora Imaging Network (MAIN) in Apatity during 2015/2016 winter season have been used. The cameras system MAIN has being built in Apatity since 2008. The cameras characteristics, their mutual situation and the measurement process are described in detail in [15].

Solar wind and interplanetary magnetic field parameters were taken from the 1-min sampled OMNI data base (spacecraft-interspersed, near Earth data) of the Coordinated Data Analysis Website (http://cdaweb.gsfc.nasa.gov/cgi-bin/eval2.cgi).

Substorm presence was verified by the 10-sec sampled ground-based data of IMAGE magnetometers network (using the meridional TAR-NAL and MEK-NOR chains) and by data of Loparskaya and Lovozero magnetometers and the Apatity all-sky camera.

To study the substorm development data from the Apatity all-sky camera and the Guppy F-044C (GC) camera with field of view ~67° (images and keograms) were used.

Results

By the MAIN 2015/2016 data, 74 substorms were detected and studied. We applied the classification used in [16]. 44 substorms occurred during storms, 16 of them during the main storm phase, 17 – in the near recovery phase, 6 – in the late recovery phase and 5 – in a structured recovery phase. 30 substorms happened under non-storm conditions, 3 of them were under quiet conditions and 27 – under non-storm conditions when structures were detected in the solar wind, but they didn't provoke geomagnetic storms. Below examples of substorms during two periods: during a geomagnetic storm and during a non-storm period when a high speed stream (HSS) was present in the solar wind.

Review of the interplanetary and geomagnetic conditions

In Fig.1 two intervals of different interplanetary and geomagnetic conditions are presented: 18 – 25 January 2016 (the left panel of Fig.1) and 9-15 December 2015 (the right panel of Fig.1). From up to down the following quantities are presented: the IMF magnitude B, the IMF Bz component, the flow velocity V, the X component of the solar wind velocity V_X, the density N_p, the temperature T, and the dynamic pressure P of the solar wind, and the geomagnetic indices AE and SYM/H.

During the first period a geomagnetic storm developed. The interplanetary conditions were complicated. In the solar wind at that time several consecutive structures were observed: Sheath (the region in front of a magnetic cloud - MC), MC, a co-rotating interaction region - CIR (the region in front of a SHH), and HSS. The boundaries of these structures are marked in the left panel of Fig.1 by solid vertical lines. In front of Sheath region was an interplanetary shock reflected in the geomagnetic data by the sharp jump of the SYM/H index about 21 UT on 18 January 2016, showing the beginning of the initial phase of the geomagnetic storm. The geomagnetic storm main phase began during MC, coinciding with the sharp turn of B_z southward at about 03:30 UT on 20 January 2016. SYM/H_{min} was -95 nT at 16:42 UT on 20 January 2016. Just after that CIR and HSS reached the Earth and contributed to a prolonged storm recovery phase, lasting several days. This geomagnetic storm was minor, Kp index reached 5-. On 20 and 21 January, during the geomagnetic storm, 8 substorms were registered by the system cameras MAIN: 2 during the main storm phase and 6 during the near recovery phase. The times of substorm onsets are marked in Fig.1 by dashed vertical lines. In the next sections two examples of substorms are shown: one substorm during the main phase at 15:05:20 UT on 20 January 2016 and one substorm during the near recovery phase at 20:27:00 UT on 21 January 2016.

The second example includes the passage of a high speed stream (HSS) by the Earth on 10 December 2015 (Fig.1, the right panel). The (CIR) lasted from about 00:00 UT to 10:00 UT on 10 December 2015. HSS following CIR lasted about 3 days. CIR and HSS are marked in Fig.1 by solid

vertical lines. The maximal change in the solar wind speed was about 200 km/s and its maximal value reached 650 km/s for about 1.5 days. This HSS didn't provoke a geomagnetic storm, the minimal value of SYM/H was ~ -15 nT. 5 substorms were registered on 10 December 2015 and their onsets were near the station zenith or to the North from it. The time range of the observed substorms is marked in Fig.1 by dashed vertical lines. Further below the development of one substorm, at 19:23 UT is presented.

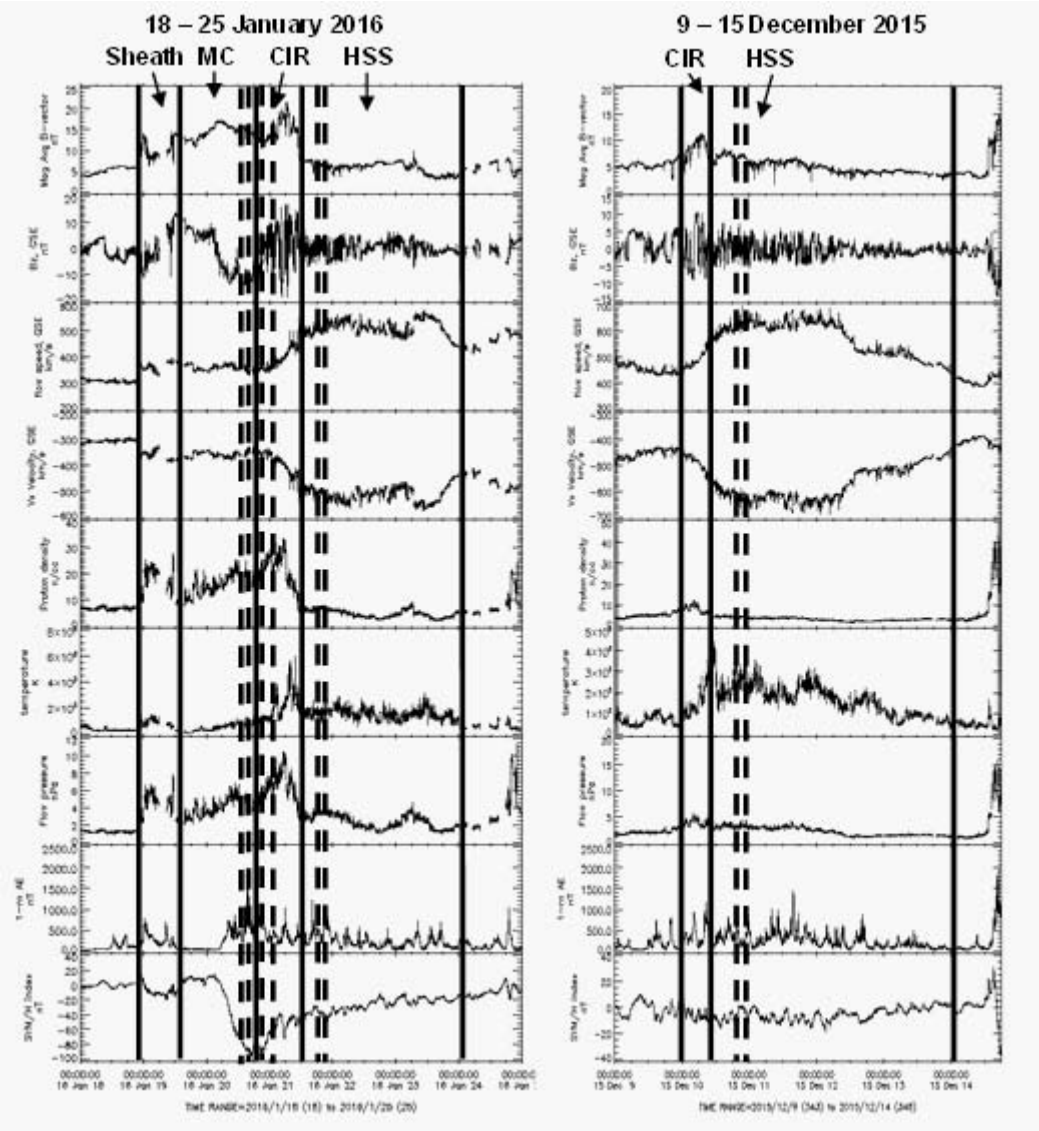

Fig. 1. Interplanetary and geomagnetic conditions during the periods: 18-25 January 2016 (the left panel) and 9-15 December 2015. From up to down: B and B_Z of IMF, V, V_X, N_p, T, and P of the solar wind, and the geomagnetic indices AE and SYM/H. The boundaries of the structures in the solar wind at the time of the examined storms are indicated by solid vertical lines. The times of the observed substorms are marked by dashed vertical lines.

Substorm at 15:05:20 UT on 20 January 2016

The aurora dynamics during the substorm on 20 January 2016 according to the all-sky camera and GC camera data is presented in Figure 2. The top panel shows some all-sky camera images from 15:05:20 to 15:55:00 UT, the left bottom panel presents the GC camera images from the same times, and the right bottom panel - the all-sky (up) and the GC (down) keograms from 15 to 16 UT. This substorm occurred during the main storm phase, to the South from the station zenith. First substorm auroras arised to the South from zenith, in the field of view of both cameras in 15:55:20 UT. The bulge development is seen. The bright aurora stayed in the South part of the field of view and after several intensifications about 15:30 UT the bulge expanded in North direction and occupied the whole field of view. The value of SYM/H index at the moment of substorm onset was ~ -87 nT.

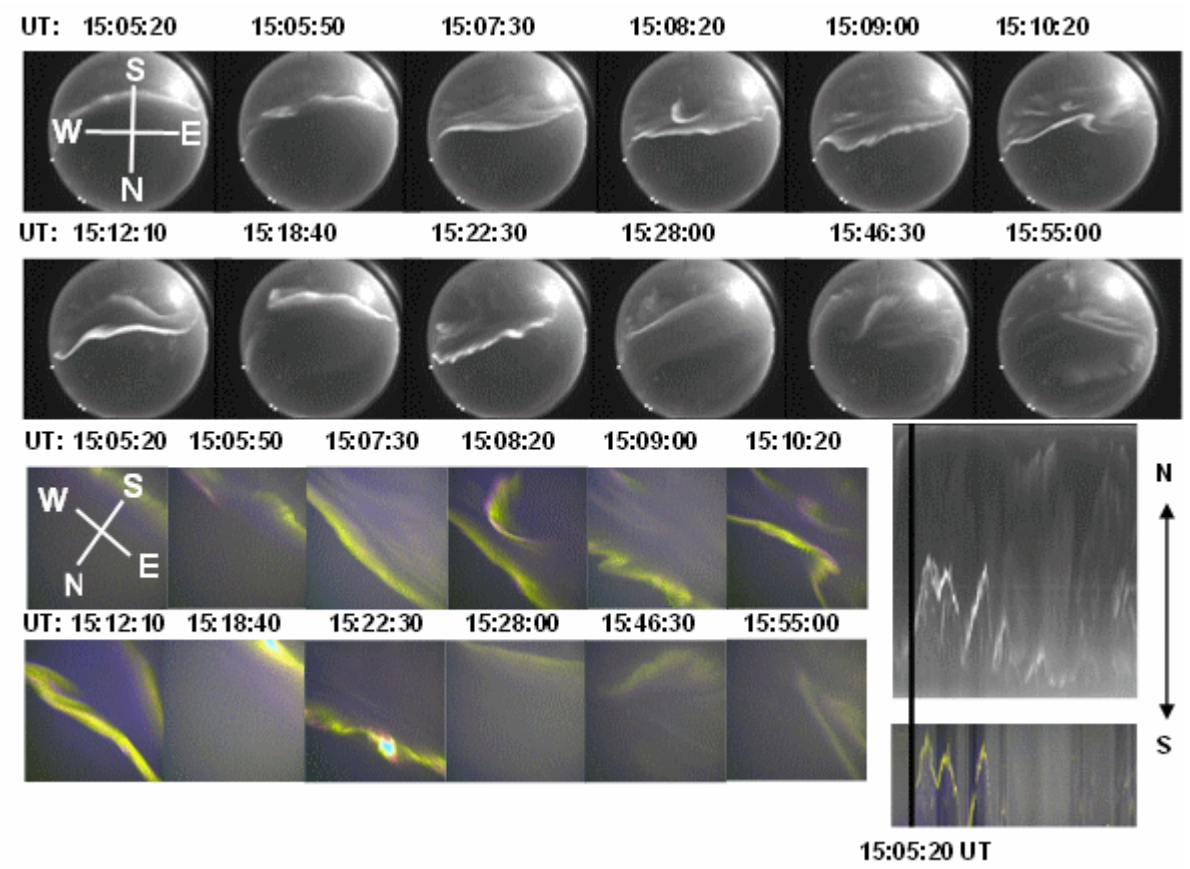

Fig. 2. Aurora dynamics during the substorm on 20 January 2016 at 15:05:20 UT by chosen all-sky images (two upper rows) and GC camera images (the third and fourth images row below to the left). The world directions are marked in the first image of each camera. The all-sky (up) and GC (down) keograms from 15 UT to 16 UT are shown to the right in the bottom panel. The substorm onset seen from the station is marked by a solid vertical line.

Substorm at 20:27:00 UT on 21 January 2016

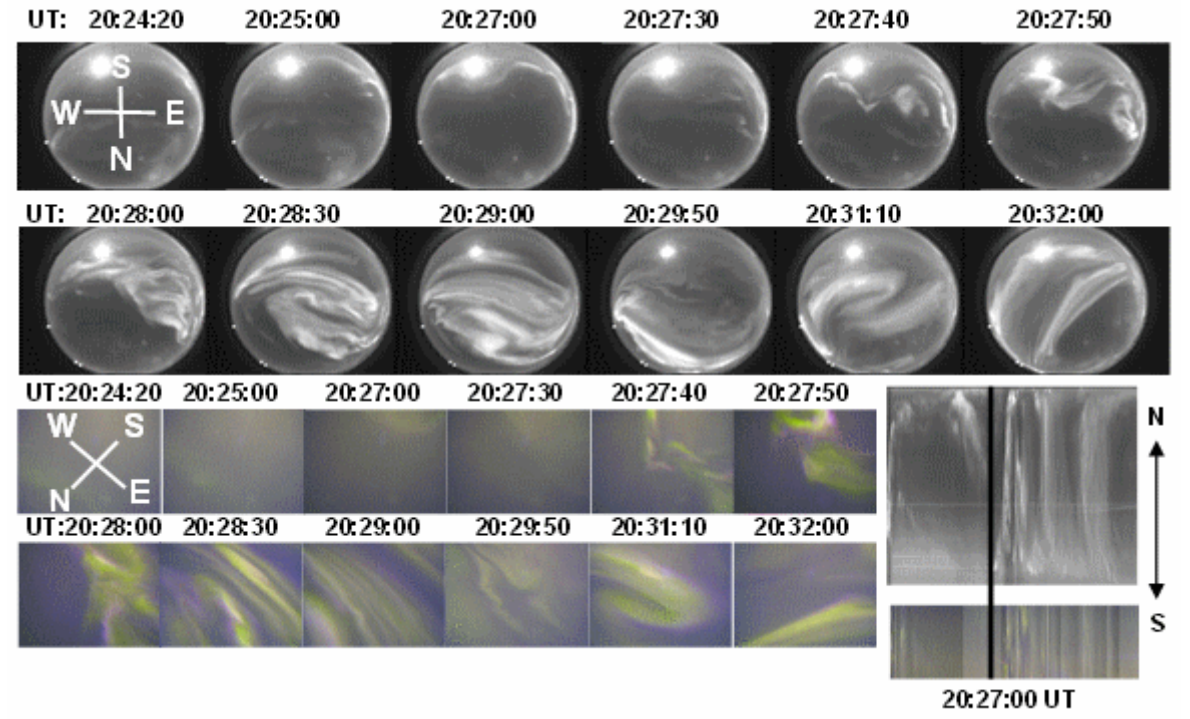

Fig. 3. Development of the substorm at 20:27:00 UT on 21 January 2016 by all-sky and GC cameras data. The format is the same as the one in Fig. 2.

In Fig. 3 the auroras dynamics during the substorm on 21 January 2016 at 20:27:00 UT by chosen all-sky images (two upper rows) and GC camera images (the third and fourth images row below to the left). The all-sky (up) and GC (down) keograms from 20 to 21 UT are shown to the right in the bottom panel. The substorm onset is marked by a solid vertical line. This substorm occurred during the prolonged recovery phase, to the South from the station zenith. Substorm auroras are seen first in the all-sky image at 20:27:00 UT near the South border of the field of view. After that a fast bulge expansion in North direction is seen. In the GC camera images bright auroras are seen first at 20:27:40 UT. The auroral bulge occupied the whole field of view at 20:28:30 UT. The value of SYM/H index at the moment of substorm onset was ~ -37 nT.

Substorm at 19:23:00 UT on 10 December 2015

The development of the substorm at 19:23:00 UT on 10 December 2015 is shown in Fig.4. The format of the figure is the same as the one of Fig.2. The substorm originated in non-storm conditions, during the passage of a HSS by the Earth. Its onset was near the station zenith, and it is seen in both cameras images. The bulge expansion in all directions is seen till substorm aurora covered the whole field of view at 19:26:30. The value of SYM/H index at the moment of substorm onset was ~ -7 nT.

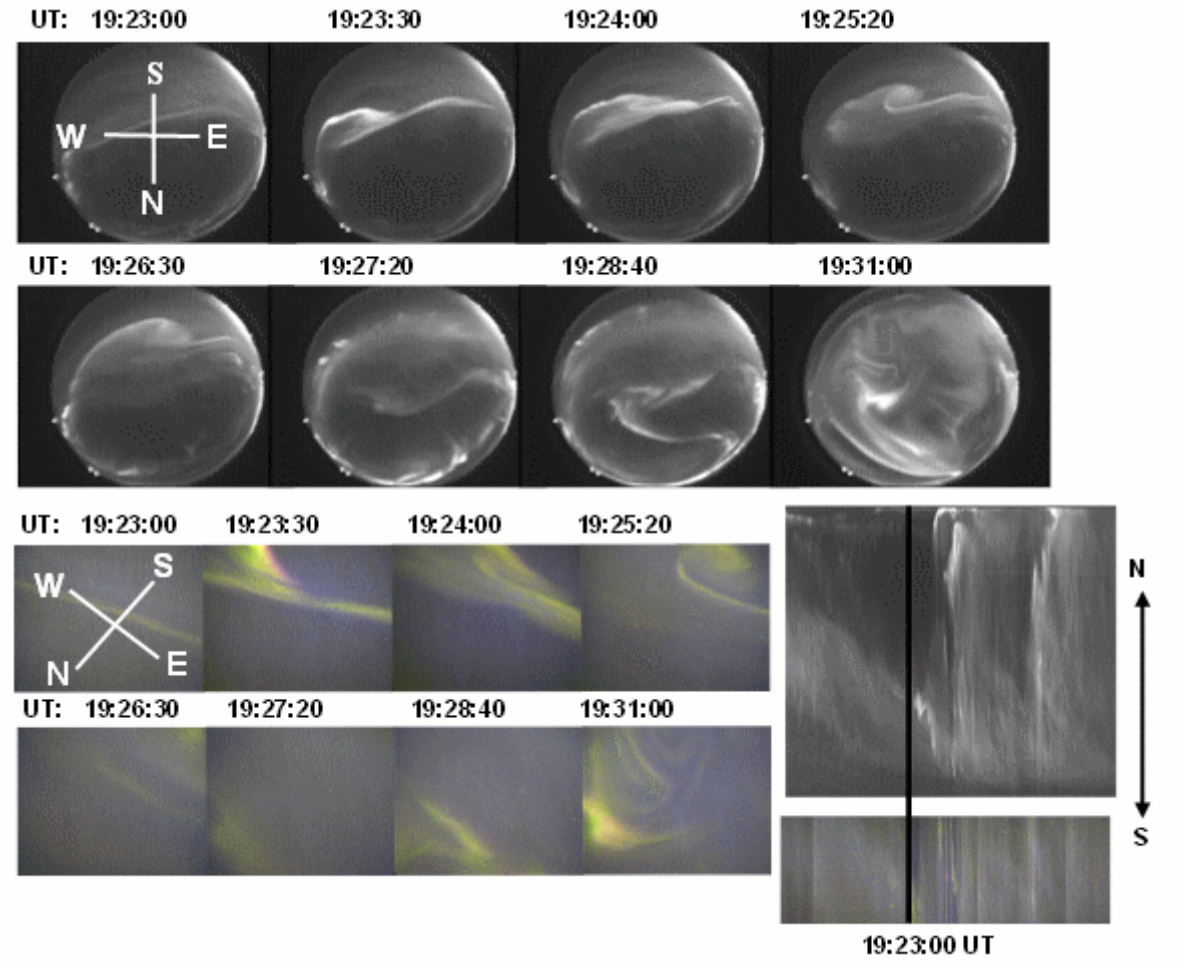

Fig. 4. Substorm development at 19:23:00 UT on 10 December 2015 by all-sky and GC cameras images and keograms. The format is the same as the one of Fig.2. The substorm onset was near the station zenith, and the bulge expansion in all directions is seen till substorm aurora covered the whole field of view at 19:26:30.

Conclusions

We studied substorms registered during the winter season 2015/2016 by the cameras system MAIN in Apatiti. 74 substorms were identified and reviewed. The results about the substorm characteristics and development confirm on the whole our findings regarding examinations of substorms during other observational seasons (e.g. [16]).

The substorms, originated during the main storm phase or in the near recovery phase, occurred to the South of Apatity (64.27°N CGM Lat.), and substorm auroras expansion to North was observed. For substorms during the late recovery phase auroras were observed to the North of the Apatity station, and their motion from North to South was registered. The boundary between both types of substorms in terms of SYM/H index is in the range 30-50 nT. Regarding the substorms characteristics the substorm onset of such substorms was usually near the station zenith and the bulge expansion in all directions could be observed. For substorms during a structured storm recovery phase or during "non-storm conditions with structures of solar wind" auroras may occur to the South or to the North from the station zenith depending on the stage of geomagnetic disturbance (mainly on the SYM/H value). The onset of substorms in quiet conditions was usually to the North from the station zenith (often near or out the field of view boundary) and auroras movement from North to South could be seen.

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