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VARIATIONS OF SUBSTORMS CONNECTED WITH DIFFERENT SOLAR WIND CONDITIONS

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Abstract

All-sky cameras data at Kola Peninsula from 2012/2013 winter season have been used to study the variation of substorm development in different conditions of interplanetary medium. Solar wind and interplanetary magnetic field parameters were taken from CDAWeb (http://cdaweb.gsfc.nasa.gov/cdaweb/istp_public/). Using WIND satellite data for the examined periods, the different solar wind streams were revealed: recurrent streams from coronal magnetic holes (RS) and magnetic clouds (MC) connected with non-stationary processes at the Sun. It is known that these solar wind structures are the sources of geomagnetic storms. Furthermore, the storms originating from these sources differ in intensity, recovery phase duration, etc. We investigated substorm development during storms caused by different sources in the solar wind. Substorm onset time and further development were verified by ground-based data of IMAGE magnetometers network and by data of all-sky cameras at Apatity and Lovozero. The particularities in behaviour of substorms observed during storms connected with solar wind recurrent streams and with magnetic clouds are discussed.

Introduction

Substorms are a specific phenomenon, related to a number of processes in the magnetosphere and ionosphere, generalized by Akasofu [1]. It was established that the substorm development goes on in the following way: the substorm expansion phase begins with the flash of one arc, usually the most equatorial one between the existing already discrete auroral arcs. After this the auroral bulge - an area occupied by bright, short-lived arcs, forms. It is expanding in all directions, mainly toward the pole, to the West and to the East [2, 3]. At the time of maximal stage of substorm development the auroral bulge reaches its greatest width and occupies a maximum area. Further, during the recovery phase, the auroral bulge begins to shrink, its polar edge moves to the equator and, the South one – to the pole, the bright discrete arcs degenerate into irregular strips and fade [4, 5].

It is known, that the substorm generation and development depends on the conditions in the solar wind [e.g., 6, 7, 8]. The solar wind conditions include the solar wind parameters values, as well as the presence of different solar wind streams and their structure [9].The solar wind streams can be recurrent streams (RS) originating from coronal magnetic holes, characterized by a 27-day recurrence, which predominate during solar minimum [10], and magnetic clouds (MC) originating from coronal mass ejections (CME) giving rise to sporadic flows, generated more often during a solar maximum [11, 12]. These solar wind structures are usually the source of geomagnetic storms that differ by their main characteristics depending on the generating structure. Therefore the substorms arising during different solar wind flows or under quiet conditions will differ by substorm onset location latitude, substorm polar edge latitude, auroral bulge extent etc.

Apatity is settled at auroral latitudes. Its geographic coordinates are: 67.58ºN, 33.31ºE, and the corrected geomagnetic ones – 63.86ºN, 112.9ºE. This location is expedient to examine the variety of substorms.

The goal of this work is to study substorm development as seen from Apatity under different interplanetary and geomagnetic conditions.

Instrumentation and data used

All-sky cameras data at Kola Peninsula from the 2012/2013 winter season have been used. The all-sky cameras observational system has being built in Apatity since 2008. It comprises 5 all-sky cameras with different fields of view providing simultaneous observations from spatially separated points. The cameras characteristics, their mutual situation and the measurement process are described in detail by Kozelov et al. [13, 14].

Solar wind and interplanetary magnetic field parameters were taken from CDAWeb (http://sdaweb.gsfc.nasa.gov/cdaweb/istp_public/). WIND satellite data revealed different solar wind streams: recurrent streams from coronal magnetic holes (RS) and magnetic clouds (MC) connected with non-stationary processes at the Sun or quiet conditions for the examined periods.

Substorm onset time and further development were verified by ground-based data of IMAGE magnetometers network (using meridional chains), Lovozero and Loparskaya magnetometers and by data of Apatity all-sky cameras.

The measurements during 2012/2013 season were examined together with the interplanetary conditions during the measuring periods. The recurrent streams and magnetic clouds were detected. The substorms developed over Apatity were identified and the solar wind conditions during these substorms times were verified. Three typical cases were chosen presenting the variety of substorm developments over Apatity: during a magnetic cloud under highly disturbed conditions, during a recurrent stream under disturbed conditions and in non-storm time, under quiet conditions.

Results

Case 1: 17.03.2013.

On 17.03.2013 a magnetic cloud passed by the Earth. Some solar wind and interplanetary magnetic field (IMF) characteristics by WIND are presented in fig.1. The straight vertical lines mark the boundaries of Sheath (06-15 UT on 17 March 2013) and MC (15 UT, 17 March – 6 UT, 18 March 2013) on 17-18 March 2013. A geomagnetic storm developed during this time. The Dst index reached -140. Under these highly disturbed conditions, during the main phase of the storm, two consecutive substorms were generated in 18:28 UT and 18:39 UT, 17 March 2013. The time of the substorms is marked by the dotted line in fig.1. The substorms generation and further development can be traced out through the magnetic field X-component records of the stations of the longitudinal chain TAR-NAL presented in the upper panel of fig.2. In the lower panel of fig.2 the progress of the magnetic field components registered in 2 stations close to Apatity, Loparskaya and Lovozero, are presented. The substorms developed during one of the most disturbed periods of the day. They were observed from Apatity. The all-sky camera registered the substorm onset and further development. In fig.3, chosen images of the substorm development are shown. The substorm beginning as seen from the station, the polar edge movement to the North, reaching the station zenith (18:32 UT) and surpassing it, the second intensification in 18:39:40 UT and its travel to North, the bulge expanding in the whole field of view are seen. The world directions are marked in the first image. The universal time is written above each image.

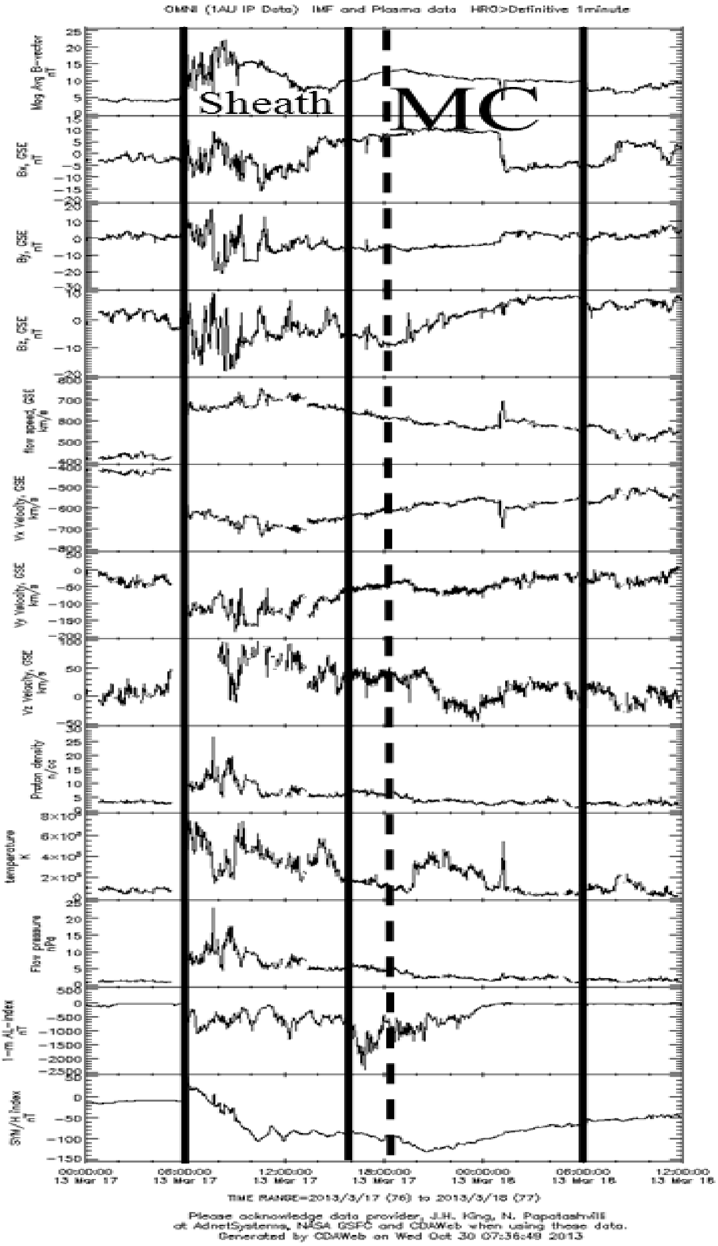

Fig. 1. IMF components, solar wind velocity and some other parameters, characterizing the geomagnetic conditions on 17-18 March 2013. The straight vertical lines point out the boundaries of Sheath and MC. The dotted line mark the time of the substorms development

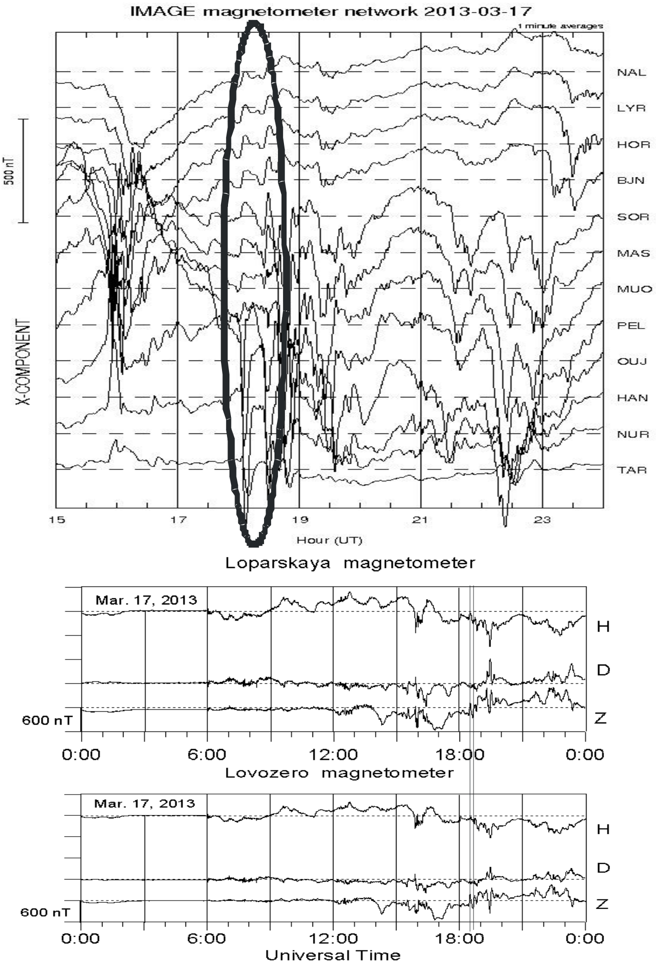

Fig. 2. X-component of the magnetic field by the stations of the TAR-NAL longitudinal chain on 17 March 2013 (up). The studied substorms are pointed out by an elipse. And: magnetic field components by Loparskaya and Lovozero stations (down). The straight lines mark the beginning of the consecutive substorms in question

Case 2: 29-30 March 2013.

During 29-31 March 2013, a recurrent stream (RS) in the solar wind was observed. The CIR region lasted from 3 to 18 UT on 29 March, and the recurrent stream – from 18 UT on 29 March to 14 UT on 31 March 2013.

The recurrent stream caused a geomagnetic storm with minimal D_{st}=-65 nT. The conditions can be considered as disturbed. Three substorms developed during RS: two substorms during the main phase of the storm (in 18:28 UT and 23:08 UT, 29.03.2013, Dst=-45÷-50 nT) and one – during the recovery phase (in 19:08 UT, 30.03.2013, Dst=-40 nT). In fig.4 some images from the first substorm development during the main phase of the geomagnetic storm are presented. The auroral oval emissions were lying over Apatity latitudes. Just before the substorm onset in 18:28 UT the arcs were moving to the South. During the bulge formation its polar edge moved in S-N direction, reaching zenith in 18:31:10 UT. In 18:31:20 UT the polar edge surpassed zenith location and after 18:32:40 UT the whole field of view was occupied by the auroral bulge forms. The second substorm followed the same behavior.

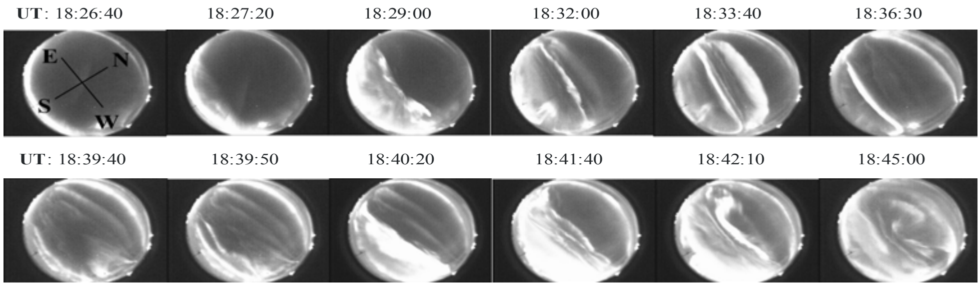

Fig. 3. Chosen all-sky camera images presenting the substorm beginning and development as seen from Apatity on 17 March 2013, during the main phase of a geomagnetic storm generated by MC. Substorm beginning, polar edge movement to the North, surpassing station zenith, the second intensification in 18:39:40 UT and its motion to North, the bulge expanding in the whole field of view are seen

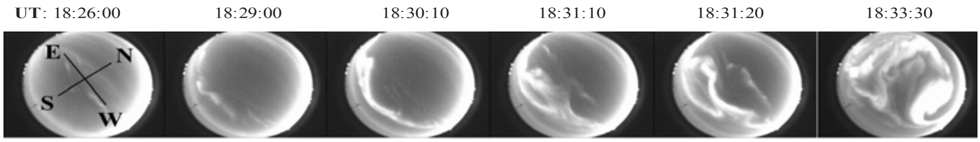

Fig. 4. Selected images of the substorm onset and development during the main phase of a geomagnetic storm caused by RS on 29 March 2013. The substorm onset to the South of the station, the bulge formation,the polar edge of the bulge motion in S-N direction and the bulge expansion over the whole field of view are observed

The picture of the third substorm development looked different (fig.5). Chosen images of the substorm development in 19:11:20 UT on

30.03.2013 during the recovery phase of the geomagnetic storm associated with RS are shown in fig.5. The substorm onset was to the North of Apatity and the expansion of the South part of the substorm bulge is observed from the station.

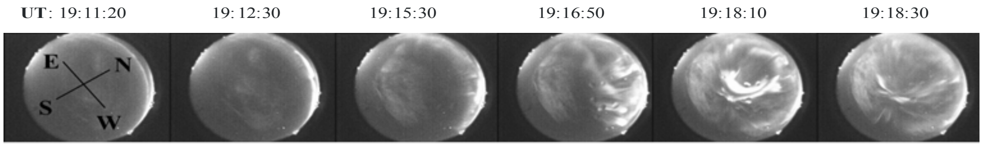

Fig. 5. Some images of the substorm development from 19:11:20 UT on 30.03.2013 during the recovery phase of the geomagnetic storm associated with RS. The substorm onset is to the North of Apatity and the motion of the South edge of the substorm bulge in N-S direction is observed from the station

Case 3: 10.04.2013.

On 10 April 2013 a substorm occurred in non-storm, quiet conditions. The auroral oval lied at higher latitudes, auroral activity was seen in the Nortern part of the field of view. The substorm onset was in 21:28 UT at the South border of the auroral oval, to the North from Apatity. The South edge of the auroral bulge was seen to travel to the South reaching Apatity zenith about 21:33:00 UT. This substorm development was presented by chosen images in fig. 6.

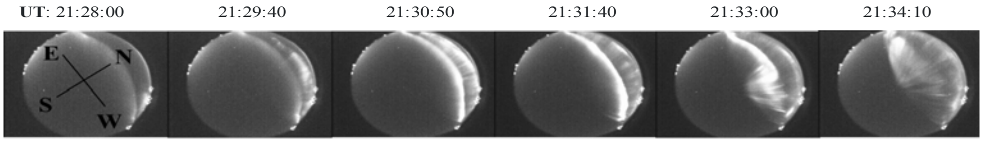

Fig. 6. Images of a substorm development on 10.04.2013, under quiet conditions. The substorm onset was to the North of Apatity and the South edge of the bulge was seen to move in N-S direction in the field of view

Discussion

We studied three cases of substorm generation and development under different conditions. In the first case, the geomagnetic conditions were highly disturbed. A magnetic cloud passing by the Earth caused a strong geomagnetic storm, with minimal value of D_{st} index -140 nT. The auroral oval was located at lower latitudes, to the South of Apatity. Both examined substorms occurred consecutively during the main phase of the storm. Their onset locations were as well to the South of Apatity. Thus, the polar edge of the auroral bulge was observed to move fast towards North, to reach and surpass the zenith. After the second intensification, the substorm bulge spread over the whole field of view, the station staying inside the bulge.

In the second case, the geomagnetic conditions were also disturbed. There was a recurrent stream in the solar wind. A geomagnetic storm was generated, with minimal Dst=-65 nT. Three substorms were examined. Two of them developed during the main phase of the storm. The substorm onset was to the South of Apatity and during the auroral bulge evolution the polar edge of the bulge moved in S-N direction over the station. The third substorm developed during the recovery phase the storm arising from RS. The auroral activity was to the North from the station and the movement of the equatorial edge of the substorm bulge could be seen in N-S direction before the spread of the bulge all over the field of view.

Case 3 represents a substorm generated in quiet conditions. In this case the auroral oval was at higher latitudes, to the North of Apatity. The substorm onset was to the North of the station, and during the bulge development, the motion of the equatorial edge of the bulge was seen in the field of view.

Therefore our results confirm that in disturbed geomagnetic conditions, when storms are generated, the auroral oval lies at lower latitudes. Thus the substorm onset location is to the South of Apatity and the motion of the polar edge of the substorm bulge can be seen moving in S-N direction over the station. And vice versa, under quiet conditions or during the recovery phase of a geomagnetic storm, the auroral oval is located at higher latitudes, to the North of Apatity. The substorm arise to the North and during the bulge expansion the movement of the its equatorial edge in N-S direction can be observed.

Conclusions

We investigated substorm development during storms caused by different sources in solar wind and during quiet conditions using observations of auroras in Apatity during 2012/2013 winter season.

It is shown that 2 types of substorm development occur over Apatity.

First type: substorm onset is to the South of Apatity, and the "usual" development of the substorm bulge is seen – from South to North; the polar edge of the bulge is observed to pass over zenith.

Second type: the auroral oval is situated at higher latitudes, substorm generates to the North from Apatity, and the movement of the auroral bulge to the South is seen from Apatity, i.e. the equatorial edge of the auroral bulge is observed.

It is shown that the first type of substorm development over Apatity happens during geomagnetic storms, associated with both magnetic clouds and high speed recurrent streams of the solar wind.

The second type of substorm development is observed during quiet (non-storm) conditions or during the storm recovery phase.

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ИЗМЕНЕНИЯ ПРИ СУББУРИ, СВЪРЗАНИ С РАЗЛИЧНИ УСЛОВИЯ В СЛЪНЧЕВИЯ ВЯТЪР

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Резюме

За изследване на измененията в развитието на суббурите при различни условия в междупланетното пространство са използвани данните от all-sky камерите в Колския полуостров през зимния сезон 2012/2013 гг. Параметрите на слънчевия вятър и междупланетното магнитно поле са взети от CDAWeb (http://cdaweb.gsfc.nasa.gov/cdaweb/istp_public/). Използвайки спътникови данни от WIND за разглежданите периоди, са намерени случаина различни потоци в слънчевия вятър: рекурентни потоци от коронални магнитни дупки (RS) и магнитни облаци (MC), свързани с нестационарни слънчеви процеси. Нещо повече, магнитните бури, възникнали от тези източници, се различават по интензивност, по продължителност на на фазата на възстановяване и т.н. Разгледано е развитието на суббури по време на бури, породени от различни източници в слънчевия вятър. Времето на възникването и по-нататъшното развитие на суббурите са потвърдени по наземни данни от мрежата от магнитометри IMAGE по данни от all-sky камерите в Апатити и Ловозеро. Дискутирани са особеностите в поведението на суббурите, наблюдавани по време на магнитни бури, свързани с рекурентни потоци и магнитни облаци.