Dayside auroral activity as a possible precursor of substorm onsets: A survey using Polar ultraviolet imagery

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Abstract. We have analyzed the dayside auroral oval, with particular emphasis on the postnoon aurorally active region, prior to the onset of isolated substorms using images acquired from the ultraviolet imager (UVI) on board the Polar spacecraft. The UVI data set used for this investigation covers a time of approximately 3 months, from March 30 to July 13 in 1996. It is found that dayside auroral "hot spots" were active in 70 out of 95 surveyed substorm events at least 15 min before the onset, while 25 cases did not involve the dayside bright spots at all. Of the 70 cases with dayside activity during substorms, 51 cases of the dayside events were found to be spatially confined and showed little discernible changes prior to an active substorm onset, while only six cases were found to be in association with apparent eastward propagation through the dusk sector to the nightside prior to a substorm onset. This statistical result indicates that most of the postnoon bright spots are spatially confined in longitude and that only a few candidate cases are possibly associated with substorms triggering. It also suggests that dayside auroral bright spots are distinct features from the nightside auroral substorms. These results suggest that the physical processes responsible for the dayside auroral bright spots are different from those responsible for the nightside substorm activity.

1. Introduction

An auroral substorm is an optical representation of the magnetospheric substorm in the high-latitude nightside ionosphere. The concept of the auroral substorm dates back to the early 1960s as first introduced by Akasofu and Chapman [1961]. Later, through detailed study of all-sky camera observations from an array of ground stations, Akasofu [1964] outlined a sequence of development stages for the global auroral substorm. This pioneering work has propelled an intensive research on auroral substorms [see, for example, Rostoker et al., 1980]. A substorm is generally categorized into three major phases [McPherron, 1979]: the growth phase, the expansion phase, and the recovery phase. The growth phase involves a time of limited optical auroral activity during which arcs move equatorward and may fade before the onset [Pellinen and Heikkila, 1978]. The expansion phase begins with a sudden localized brightening of the arcs near local midnight. This is then followed by a poleward expansion resulting in the formation of bulges [Rostoker et al., 1987]. During this phase a surge is often seen on the westward edge of the bulge, which progressively moves westward and is hence called the westward traveling surge (WTS). At the end of an expansion, the auroral forms become less intense, and the poleward and equatorward expansions start contracting, signaling the start of a recovery phase.

Auroral activity in the day sector is also one of the key features in an auroral distribution. Previous observations have identified two preferred positions for the occurrence of dayside optical intensification: one in the 1400-1600 MLT sector [Cogger et al., 1977; Evans, 1985] and a much weaker "warm spot" in the prenoon sector [Meng and Lundin, 1986; Newell et al., 1996a]. The strong postnoon dayside optical auroral intensification appears to coincide with the maximum region I upward field aligned currents (FAC) in the 1400-1600 MLT sector [Iijima and Potemra, 1978].

Early synoptic particle studies were somewhat conflicting as to the evidence of a distinct afternoon hot spot; Evans [1985] found one, while Gussenhoven et al. [1985], using electron data with a complete energy cova-
verage including the bulk of cusp electrons, did not. This discrepancy was largely resolved by a massive statistical study of discrete electron acceleration events by Neveu et al. [1996a]. Although the 1400-1600 MLT region does not generally include more total electron energy flux input than the cusp region, it does include many weak electron acceleration events, with average acceleration of a few hundreds of eV. Unlike nightside activity, these weak postnoon electron acceleration events are approximately equally common for northward and southward interplanetary magnetic fields (IMF) [Neveu et al., 1996a] and, also contrarily to nightside auroral activity, are actually more common in sunlight (summer) than in darkness (winter) [Neveu et al., 1996a].

Less attention has been given to the morning “warm” spot, but it appears to coincide with the “mantle” or “region 0” currents out of the ionosphere prenoon [Neveu et al., 1996a]. Unlike the postnoon hot spot, the morning warm spot follows the same pattern as the nightside oval; that is, it is much less active for northward IMF and is greatly suppressed in sunlight.

The dynamic of dayside auroral phenomenon has been studied using the Viking ultraviolet imager (UVI) [Murrhee et al., 1981; Anger et al., 1987]. Auroral bright spots observed in the 1400-1600 MLT sector sometimes exhibit a spatially periodic pattern and can last for a few minutes [Lui et al., 1989]. Meng and Lundin [1986], through analysis of the imaging data from Defense Meteorological Satellite Program (DMSP), showed examples of clear topological disconnection between the dayside and the nightside discrete aurorae. They also found poor correlation between the midday auroral activity and the concurrent nightside substorm, suggesting the existence of two independent processes responsible for the dayside and nightside activities [cf. Akasofu and Kan, 1980]. Viking image data have also indicated that the auroral bright spots in the 1400 1600 MLT sector can occur with or without the appearance of a nightside substorm [Lui et al., 1989].

In a recent study of Viking UVI data, Elphinstone et al. [1991] found a case of rapid motion of dayside activity to the nightside prior to an auroral substorm onset. Based on this observation, they suggest that the dayside event is affected by the same solar wind disturbances which later affect the nightside magnetospheric dynamo, and thus the dayside activity should be included in the whole picture of an auroral substorm. This type of dayside activity appearing shortly before an auroral substorm onset has recently earned attention because it has a profound impact on the current knowledge of auroral substorm mechanisms predicted by many theoretical models, and, most important, it may provide a means to predict a substorm for space weather forecasting. However, Elphinstone et al. [1991] conclusion, associating the dayside auroral activity with the subsequent nightside auroral substorm, is not conclusive, because their investigation was subject to a limited number of images and thus is not sufficient to provide a statistical view. Furthermore, Lui et al. [1995] reported the observations of a substorm on July 24, 1986, which exhibited precursory auroral head-like activities prior to the substorm onset. Although the auroral head formation may be related to a disturbance originating from the noon sector propagating westward along the auroral oval toward the morning sector, they noted that the substorm onset location was distinctly different from the location of auroral heads. This event casts doubt on the association between the mechanism activating auroral heads and the substorm process. To further examine this problem, we have studied a new set of auroral images recently acquired from the UVI on board the Polar satellite focusing on the causal relation between day and night aurorae.

As discussed above, particular attention is given in this paper to the spatial and temporal changes of large-scale dayside auroral bright spots in the afternoon sector prior to a substorm onset. In section 2, we briefly describe the Polar UVI instrument and then present the UVI results in a case by case manner. A statistical survey of the postnoon bright spot during substorm times will be given in section 3. The discussion of the results will be given in section 4, followed by a brief conclusion.

2. The UV Imager and Some Case Studies

2.1. The Polar Ultraviolet Imager

The data used for this investigation are taken by the UVI imager [Torr et al., 1995] on board the Polar satellite. The Polar UVI is an anastigmatic three-mirror instrument with a narrow-angle (8° circular field of view) and a large-aperture (f/2.9) design. With the aid from a despun system, the UVI is capable of monitoring the northern hemisphere auroral oval for about 9 hours of every 18-hour orbit and providing approximately 2400 images (37-s telemetry rate) with a resolution of 0.04° per pixel. The optical sensor operates from 1300 to 1900 Å, and it combines with specially designed narrow-bandwidth interference filters to perform specific measurements. The major filters operated on the UVI are the ones centered at 1304 and 1356 Å for atomic oxygen lines and the short Lyman-Birge-Hopfield (LBHS) filter centered at ~1500 Å and the long Lyman-Birge-Hopfield (LBHL) filter centered at ~1700 Å for molecular nitrogen lines.

2.2. Presentation of Three Examples

Before showing and interpreting the UVI images, one must bear in mind that there are some limitations of optical data acquired from the Polar UVI imager. The Polar UVI provides a spatial resolution of 0.04° per pixel, which corresponds to about 30 km at 100-km height for images taken at 6 Earth radii and 40 km at 8 Earth radii. Fine auroral structures such as discrete auroral
Plate 1. A sequence of 24 auroral images at short Lyman-Birge-Hopfield (LBHS) band acquired from the Polar ultraviolet imager (UVI) on April 9, 1996, from 1415:38 UT to 1502:15 UT. Images are transformed into the geomagnetic coordinate system with 1200 MLT on the top and dawn on the right. The magnetic latitudes of 60°, 70°, and 80° are included as concentric circles around the north pole. The color-coded bar shows the raw instrument counts. The midday bright spots extended from 0400 MLT to 1600 MLT appeared as early as an hour (not shown) before the substorm onset (at 1440 UT) and stayed there for another hour (not shown) after the onset.
Plate 2. A sequence of 24 auroral images at long Lyman-Birge-Hopfield (LBHL) band acquired on April 6, 1996, from 1253:08 UT to 1329:56 UT, showing spatially confined afternoon bright spots roughly between 1300 MLT and 1600 MLT. This event is similar to the one in Plate 1 except for the absence of auroral activity in the prenoon sector.

arcs which have typical latitudinal widths of less than 1 km are not resolved by the UVI and hence cannot always be distinguished from the less structured diffuse aurorae, except through their dynamic behavior. Temporal resolution is another key factor that must be considered before attempting to interpret the optical data. The UVI imager has a repetition rate of 37 s and alternates several filters and varying exposure times. The most common operational mode can achieve a time resolution from 37 s to about 6 min, with 2.5 min on average. Therefore transient auroral features which last for only a few minutes may be subject to this type of limitation. In this data presentation we will show three typical types of dayside auroral forms during substorm onset.

2.2.1. Substorm onset with accompanying
Plate 3. A sequence of 24 auroral images at LBHS band acquired on June 10, 1996, from 0230:56 UT to 0304:03 UT, showing no dayside auroral activities before and after a substorm onset (~0253 UT). A long-lasting precursor can be seen before the onset.

dayside bright spots. Plate 1 shows a sequence of 16 consecutive (about 2.5 min apart) false-color auroral images at LBHS band taken on April 9, 1996, from 1415:38 UT to 1502:15 UT. Each image has been transformed into the PACE (Polar Anglo-American Conjugate Experiment) geomagnetic coordinate system defined by Baker and Wang [1989]. The magnetic local time (MLT) is divided into 12 time zones separated by straight lines such that the vertical line represents the noon-midnight meridian and the horizontal line denotes the dawn-dusk meridian. The universal time that corresponds to the time when the image was taken is labeled.
Plate 4. A sequence of 24 auroral images at LBHS band acquired on April 12, 1996, from 0729:40 UT to 0802:47 UT, showing the development of 1400-1600 MLT bright spots about 20 min before a substorm onset (at 0752 UT). Of particular interest is that the eastward portion of the bright spots has progressively extended into the evening sector prior to the onset.

on top of each image. A color-coded bar is also provided on the right of the images to show the raw instrument count-rate values. This sequence of images shows a typical presubstorm auroral distribution with clear dayside bright spots. It should be noted that the background luminous area in the dayside is the airglow caused by the Sun. The substorm onset occurs at 1440 UT, which can be identified by a sudden brightening near midnight, immediately followed by a poleward expansion at ~1442 UT. The dayside aurora is distributed over 12 hours of local time from 0400 MLT to 1600 MLT along the oval, with a maximum bright spot in the 1200-1400 MLT sector. The bright spots sometimes exhibit a weak periodic pattern in longitude which resembles the dayside bright spots observed by Viking UVI, which Lui et al. [1989] called "beads on a string." The postnoon bright spot
in the 1200-1400 MLT sector first appeared as early as 1334 UT (not shown), about an hour prior to the substorm onset, and lasted for at least another hour after the onset. One of the most interesting features resulting from this sequence of images is that this persistent afternoon bright spot was highly confined in longitude along the oval and showed no sign of eastward propagation to the nightside throughout its lifetime. The optical intensity of the bright spots at this wavelength band did not show any significant change either. Another example of dayside bright spots is shown in Plate 2. This sequence of 16 images (about 2.5 min apart) was observed on April 6, 1996, from 1253:08 UT to 1329:56 UT at LBHIL bands. In this particular event, the UVI operated at a single LBHL mode which provides the best temporal resolution of 37 s. In this event the bright spot was located at the postnoon sector roughly from 1300 MLT to 1600 MLT and persisted about 30 min before the onset (1320 UT) and another 30 min after the onset without showing any significant change in location and luminosity. The two cases illustrated in Plates 1 and 2 show a very persistent dayside intensification of auroral form before and after the substorm onset and may indicate that the source of plasma for this dayside feature is continuous and long-lasting throughout the noon region.

2.2.2. Substorm onset during a quiet dayside activity. Dayside auroral bright spots are not necessarily associated with a nightside auroral substorm because they are not always observed during substorm intervals. An example of this is shown in Plate 3 as a sequence of 16 consecutive images (about 2.5 min apart) at LBHS band taken on June 10, 1996, from 0230:56 UT to 0304:03 UT. In this event the first brightening, which was weak, occurred at 0230:56 UT in the evening quadrant covering a region of about 2 hours of MLT and has slowly drifted eastward to about 2200 MLT where a substorm onset occurred (~0753 UT). During this time period, however, the dayside auroral region which was embedded in the UV dayglow showed no sign of enhanced luminosity or bright spots. This particular event shows that an auroral substorm can be totally independent of the dayside activities.

2.2.3. Substorm onset preceded by an eastward motion of postnoon bright spot. Through searching from the UVI database, we found a type of auroral form with an apparent propagation of dayside bright spots toward the night sector prior to a substorm onset. This event was observed on April 21, 1996, from 0729:40 UT to 0802:47 UT at LBHIS and is shown in Plate 4. In this sequence of image display the first image shows a postnoon bright spot located between 1400 MLT and 1600 MLT, which existed there for more than 30 min (not shown) before the substorm onset at 0753 UT. Note that a pseudobreakup appeared at ~0738-0740 UT. After this time (0729 UT), the eastward portion of the bright spot started to spread through the dusk sector, reaching to about 2000 MLT at 0752 UT when the substorm onset begins. There are two noteworthy features that we would like to mention. First, although the dayside bright spot has spread to the nightside, its intensity did not change significantly even after the substorm onset. Second, unlike the example given by Elphinstone et al. [1991], in this event, the dayside eastward extension does not reach the location of the substorm onset bulge. A clear disconnection between the extended dayside bright spot and the nightside substorm bulge can be seen until about 0802 UT. Subsequently, the WTS moved westward significantly, resulting in the apparent connection. This example is the best example we can find in the UVI data set to illustrate the type of apparent dayside propagation event previously reported.

3. Statistical Survey

The events presented in the previous section indicate that persistent afternoon auroral bright spots occur usually, but not always, before and after an auroral substorm onset and that they can be either in a stationary state confined in longitude or in a state of eastward expansion. It hence raises questions such as how often the afternoon bright spots appear prior to an auroral substorm and how often the eastward extension of dayside bright spots exists right before a substorm onset. These questions will be addressed in this section through a statistical survey of the UVI data set from March 30, 1996, to July 13, 1996.

The first step in our investigation is to visually define an auroral substorm and establish a time table for the auroral substorm onsets. The usual time interval between two substorms in one night ranges from 0.5 to 3 hours. However, for disturbed periods, several auroral breakup may occur in one night, and signatures of each phase may be observed simultaneously and the characteristic temporal sequence be difficult to recognize. In order to study the dayside event prior to a nightside auroral substorm only, isolated substorm events with at least 15 min of presubstorm quiet time will be considered. Two substorm events occurring within 1 hour will be considered as one event. The auroral behavior prior to substorm onset can sometimes be complex [see, for example, Elphinstone et al., 1995]. The first brightening of nightside oval sometimes can last for 10 min and then fade away [Pellinen and Heikkila, 1978]. To avoid these ambiguous features, we will adopt the conventional definition of a substorm: The onset time is determined by a sudden brightening of auroral oval in the night sector roughly between 2100 MLT and 0200 MLT, followed by a poleward expansion.

On the basis of the auroral substorm time table we have constructed, we then examine the behavior of dayside auroral bright spots, especially in the postnoon sector, and categorize them into the basic types shown in
the preceding section. A total of 95 auroral substorms was identified. Among these we found that for 72% (70 events) of auroral substorms, dayside bright spots were present prior to onset, while only 28% (25 events) of substorms were not accompanied by the dayside auroral activity (similar to the one shown in Plate 3). One should note that the afternoon auroral activity is very common in quiet times as well [Newell et al., 1996a; Brittnacher et al., 1997]. Thus this result does not imply a strong correlation between dayside bright spots and nightside auroral substorm onset. To further justify this, we also ran a random test of the occurrence rate for the afternoon auroral activity in quiet times. The quiet time is defined as a time period with an absence of an auroral substorm in the night sector. We randomly selected 95 time segments of 15 min interval each and inspected dayside auroral activity in the afternoon sector in these time segments. We found that afternoon bright spots appeared to occur in 67% (64 time segments) of the random selected quiet time periods, which is consistent with the particle observation [Newell et al., 1996a]. In the 70 dayside auroral bright spot associated substorm events, we further found that 51 events are associated with the longitudinally confined pattern as shown in Plates 1 and 2, while only six events are possibly associated with the eastward propagation event shown in Plate 4. We also found a few cases of events in which the afternoon bright spots darken or brighten during a substorm onset, but not significantly.

4. Discussion and Conclusion

Lui et al. [1989] reported that the 1400-1600 MLT bright spots which are frequently seen in global UV images from the Viking satellite during substorm events are transient features with 1-10 min of duration, latitudinal widths of about 100-200 km, and longitudinal extent of <500 km. However, this investigation from Polar global UVI images has shown a slightly different result. Generally, the location of postnoon bright spots is consistently found in the neighborhood of 1400-1600 MLT sector, and the longitudinal extent of bright spots is found to be 2 hours of MLT, on average, which agrees well with the previous observations. However, unlike the transient and spatially periodic features of the 1400-1600 MLT, the bright spots that we observed shortly before or after a substorm onset exhibit highly persistent and spatially continuous features. This distinguishing difference between the two observations may suggest that the bright spots we observed in the postnoon quadrant are different from those observed by Lui et al. [1989]. One may suspect that this difference is due to different investigation periods performed in the two studies. This means that the feature of postnoon bright spots varies in time with respect to different substorm phases. Although we have seen a few events with clearly defined spatially periodic bright spots similar to those presented by Lui et al. [1989] during substorm periods and a few events (about 10% in our survey) which show location and luminosity variations before and after a substorm onset, we question their importance, because our statistical results show that 90% of our surveyed events were quasi stationary. On the other hand, it may simply result from the difference in the spatial resolution and sensitivity of the two imagers. With a closer look at the Polar UVI images we found that isolated, enhanced bright spots are sometimes embedded in a broad region of relatively less intense warm spots (see Plate 1). The Polar UVI imager is capable of measuring weak optical emissions in the vicinity of 250 Rayleighs [Torr et al., 1995], about a few times better than its counterpart on Viking [Anger et al., 1987], and thus it may be able to pick up weak auroral emissions that cannot be seen by the Viking imager. The broad region of warm spots may be attributed to a large-scale, quasi steady interaction between the solar wind and the dayside magnetosphere, while the isolated intense bright spots may be associated with microinstabilities from within. This interesting feature of bright spots deserves further investigation. It should be noted that the term “bright spots” used throughout this paper represents the integral part of intense emission region near the 1400-1600 MLT sector. A thorough study of the postnoon bright spots and their correlation with the solar wind parameters and particle data is currently being undertaken.

The most interesting and important result that we found in this statistical survey is that the postnoon bright spots are longitudinally confined in over 90% of auroral substorm intervals. Although candidate events of dayside auroral propagation do exist in the UVI data set, they are rare. It is reported by Elphinstone et al. [1991] that the entire propagation event sequence of a dayside aurora observed by the Viking imager is dynamically short and can be completed in 5-10 min [Elphinstone et al., 1991]. The temporal resolution provided by the Polar UVI should be able to easily identify this, and yet only about 6% of substorm onsets surveyed can possibly be of this category. None of the events unambiguously show a propagation extending completely from the dayside to the substorm bulge. Moreover, from a case study of Viking UV images, Rostoker et al. [1992] showed no apparent movement of bright spots in 1300-1500 MLT sector during a substorm expansion phase. We therefore conclude that the propagation of dayside auroral bright spots toward the nightside prior to a substorm is very rare, and hence substorms are not likely to be triggered by a solar wind disturbance which propagates in a visible manner from dayside to nightside.

The present work agrees with other research indicating the disconnection of dayside auroral arcs from the nightside auroral [Meng and Lundin, 1986; Lui et al., 1989; Brittnacher et al., 1997]. These regions also respond quite differently to the effects of the IMF [Newell et al., 1996a] and to sunlight [Newell et al., 1996b]. In
this study we found persistent and localized auroral intensification in the postnoon sector before a substorm onset, which is consistent with previous observations. We also found that this type of localized auroral bright spot usually exists even after an onset and persists throughout the expansion phase. If one considers the dayside auroral activity, especially the postnoon bright spot, as a prelude to an auroral substorm, it should disappear or, at least, darken significantly in a progressive way shortly after the substorm onset. However, this is not what the UVI data show.

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