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Auroral Electrojet Event Associated With Magnetospheric Substorms*

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Abstract The auroral electrojet index is an important index in monitoring and predicting substorms. A substorms usually includes auroral breakup, auroral electrojet event marked by *AE* increase, energetic particle injection at geosynchronous orbit, mid-low latitude Pi2, *etc.* However the question whether an auroral electrojet event corresponds to a substorms remains unanswered. Using the auroral electrojet index in 2004, we analyzed five auroral electrojet events and studied their relation with substorms. The results show that there are three kinds of auroral electrojet events: (1) simultaneous rapid increase of westward auroral electrojet and eastward auroral electrojet; (2) rapid increase of westward auroral electrojet and almost unchangeable eastward auroral electrojet; (3) rapid increase of eastward auroral electrojet and almost unchangeable westward auroral electrojet. Most of auroral electrojet events correspond to substorms. However a few auroral electrojet events are not accompanied by substorms. This situation most often occurs for the auroral electrojet event in which eastward auroral electrojet dominates.

Keywords Auroral electrojet event, Geomagnetic index *AE*, Geomagnetic substorm

1 Introduction

When the south component of solar wind magnetic field has arisen, energy transferred from solar wind to the magnetosphere would be enhanced and conserved in the earth magnetotail. Once encountered with large disturbances, these energies would be released fiercely, causing strong sequential variations in the magnetosphere and ionosphere, which is called magnetospheric substorm (Akasofu, 1979; McPherron, 1991). Aurora is the most notable representation of substorms. During substorm, the quiet auroral arc might flare with great brilliance abruptly. Within about an hour, the aurora has undergone a series of temporal and spatial evolutions sequentially. Accompanied the aurora, geomagnetic disturbances also arises. The typical disturbance amplitude is 200–2000 nT.

During a typical isolated substorm, accorded with the auroral current system, the magnetic field and plasma in magnetosphere have experienced a series of distinct variations. The solar wind magnetic field rotated southward, magnetopause in the dayside eroded, and corresponding magnetic flux was delivered to the magnetotail lobe. Due to enhancement of lobe magnetic pressure, the plasma sheet thinned out and finally magnetic reconnection occurred when the magnetotail was 20–25 R_e (R_e is the radius of earth) away from the earth (Baumjohann, 2002). The high-speed ion flow produced by magnetic reconnection moved toward earth with mass, energy and magnetic flux. The flow slowed down and was braked on the boundary between magnetotail dipole magnetic field and the tailward magnetic field, *i.e*, 10–12 R_e away from earth, which has induced inertial currents along with the phenomena of magnetic field pileup and ma-

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gnetic dipole (Angelopoulos *et al.*, 1994; Shiokawa *et al.*, 1998; Cao *et al.*, 2006; Ma *et al.*, 2009). For certain reasons, cross-tail current disruption also occurred in the magnetotail region of 10–12 R_e away (Pu *et al.*, 1999; Lui, 2004). The disrupted currents became field-aligned currents, which flowed inside and outside the ionosphere in the dawn side and dusk side respectively, and then formed substorm current wedge together with the westward electrojet in ionosphere. The substorm current wedge would produce negative magnetic bay of geomagnetic H-component in the night side of high latitudes and Pi2 of low- and mid- latitudes (Meng and Liou, 2004; Cao *et al.*, 2008). These events constitute the three phases of substorm in the magnetosphere, *i.e.*, the growth phase, expansive phase and recovery phase.

During a substorm, magnetic disturbances observed from the ground beneath the aurora were positive in time interval from afternoon to evening, and negative near midnight. Assuming the currents were located in the vertex, it can be derived that the currents flowed into midnight eastward and westward separately using right-hand rule. The current movement along converged channel constituted by auroral particles with high conductivity at 120 km is called electrojet. The eastward electrojet is denoted with AU index, and westward electrojet with AL index. When the global H-component curves obtained by the magnetometers chain along auroral zone under the electrojet are superposed together, their top and bottom envelopes represent AU and AL index respectively. AE index is defined as the addition of absolute values of AU and AL index. Since onset of an independent substorm is defined by the electrojet index deviation from or reversion to its ground states, and the index ground state is defined by its quiet day variation, the growth phase corresponds to the initial period of AU and AL index tardy growth, which is caused by the DP-2 system; the expansive phase is the quick elevation period of AE index, which corresponds to the formation of new substorm current wedge; the period of AE decrease is deemed as the recovery phase. The substorm includes series of events consisting these three phases.

Auroral electrojet indexes, including AE, AU and AL are crucial physical parameters for substorm detection, prediction and study attributing to the more convenience and reliability of magnetic field detection than aurora detection. Normally, occurrence of one substorm is correlated with the burst of an auroral electrojet event. Yet, could it be reversed as that burst of an aurora event is correlated with one substorm occurrence? To find the answer of this question, we have analyzed 5 typical auroral electrojet burst events and discussed their correlation with substorm based on the aurora indexes (AE, AU and AL) in 2004 as well as the tailward energy particle detection data at geosynchronous orbit by LANL satellite.

2 Cases Analyses

In this study, the AE, AU and AL index of geomagnetic disturbances were taken from WDC for Geomagnetism in Tokyo, Japan, and the geosynchronous orbital energy electron data were acquired from the website of geosynchronous orbital satellite LANL of USA.

2.1 Auroral Electrojet Burst With Simultaneous AU and AL Variation

A number of substorms occurred on April 23, 2004. Auroral electrojet index of AE, AU and AL has been illustrated in Figure 1. The geomagnetic activity was frequent on that day, when Kp index was between 2+ and 4, and Dst index minimum was −39 nT. From Figure 1, as can be seen that there were totally 6 substorms on that day, among which there were 3 small substorms ($200 < AE < 500$ nT), 2 medium substorms ($500 < AE < 1000$ nT) and one super substorm ($AE > 1000$ nT). For these 6 substorms, the fast decrease of AL and increase of AU commenced nearly in chorus, which resulted in rapid ascendance of AE. Except for the super substorm occurring in time interval of 12:00 UT–17:30 UT, AL minimum and AU maximum of the rest 5 substorms were reached almost at the same time, which means that AU and AL turned into the recovery phase simultaneously. In the super substorm, AE reached its maximum 1117 nT at 13:13 UT, while AL reached its minimum −908 nT at 12:57 UT and AU reached its maximum 441 nT at 16:04 UT. The time duration for AU to reach its maximum later was about 3 hours lo-

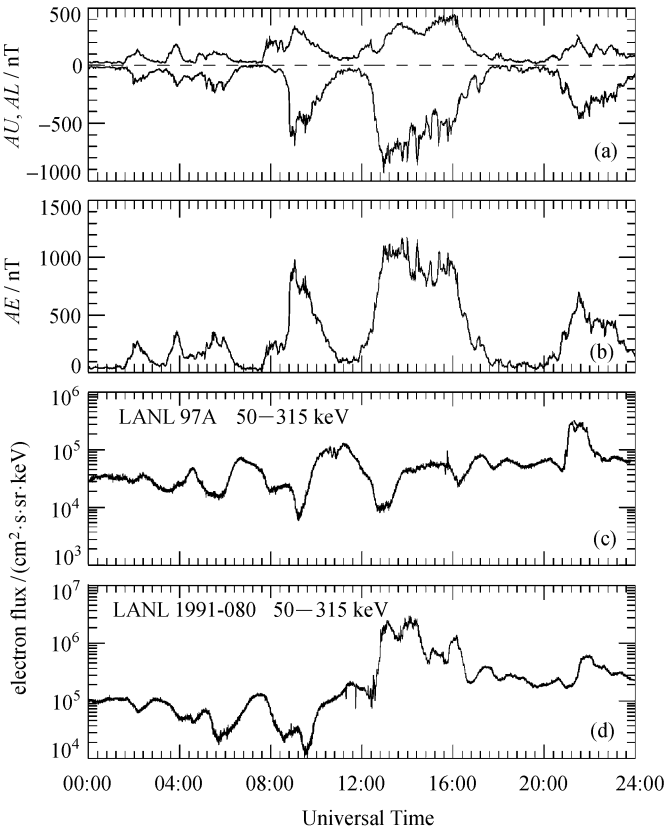


Figure 1 Auroral electrojet AU, AL (a) and AE (b) index, electron flux of 50–315 keV at geosynchronous orbit recorded by LANL 97A (c) and 1991-080 (d) on 23 April 2004.

nger than that for AL to reach minimum. However, both AU and AL recovered to their states before substorm at about 17:30 UT.

During all these 6 substorms, distinct energetic electron injections have been recorded by the geosynchronous orbital satellite. For substorms occurred at different time, the satellites which firstly detected the energetic electron injections are different, but they were all located in the night side.

2.2 Auroral Electrojet Burst of *AL* Dominance

An auroral electrojet burst has occurred in time interval of 16:50–18:50 UT on February 5, 2004. The variation of AE is similar to that of a typical substorm, but the AU and AL both behaved inconsistently with that of a typical substorm. Figure 2 gives the variation of AE, AU and AL during this auroral electrojet disturbance. AE began to increase at 16:44 UT and reached its maximum 486 nT at 17:26 UT. What is different from a typical substorm is that growth of AE index is attributed all to the variation of AL, while AU was almost unchanging and sustained at a low level. AL reached its first minimum −451 nT at 17:26 UT and then began to recover. However, during the recovery phase, AL dropped again and reached its second minimum −517 nT at 17:51 UT. Meanwhile, AU had no corresponding variation and was sustained beneath 50 nT except for a transient growth at about 17:51 UT.

An energetic electron injection was recorded by LANL at 17:10 UT in the geosynchronous orbital region. The geomagnetic data by Urumqi station (43.8°N, 87.7°E) in the night side has displayed Pi2 and a mid-latitude positive H magnetic bay. Therefore, this aurora electrojet burst was correlated with a substorm event although its variation was distinguished to a typical substorm.

During the time interval of 15:50 UT–18:00 UT on October 27, 2004, an auroral electrojet burst similar to as depicted above. Figure 3 has illustrated the variations of AE, AU and AL during this auroral electrojet disturbance. AE began to grow at 15:55 UT,

and reached its maximum 345 nT at 17:04 UT, as is consistent with the case on February 5 in which growth of AE is all contributed by AL, while AU kept nearly constant during the whole process and was sustained beneath 40 nT. The geosynchronous orbital satellite LANL-97A showed that the energetic electron flux began to grow at 16:05 UT and reached its maximum at 17:10 UT. The geomagnetic data re-

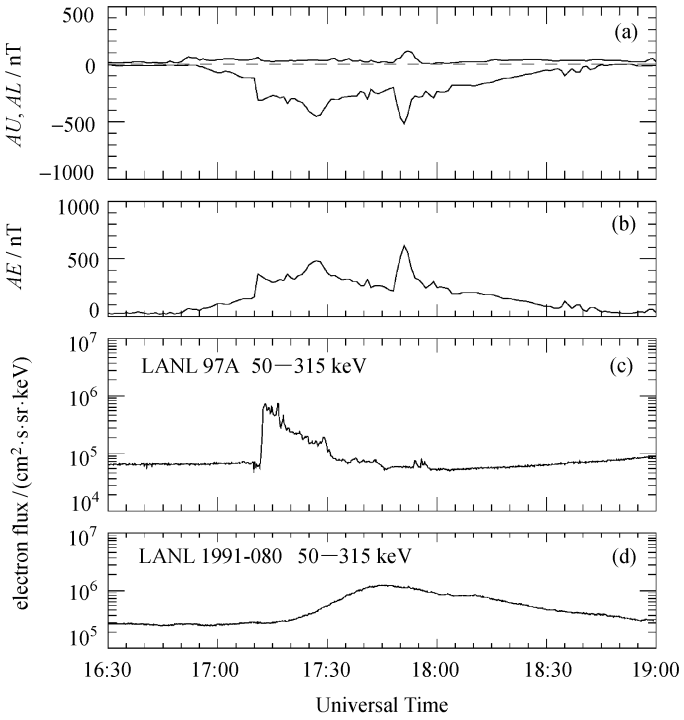


Figure 2 Auroral electrojet AU, AL (a) and AE (b) index, electron flux of 50–315 keV at geosynchronous orbit recorded by LANL 97A (c) and 1991-080 (d) during the interval of 16:30 UT–19:00 UT on 05 February 2004.

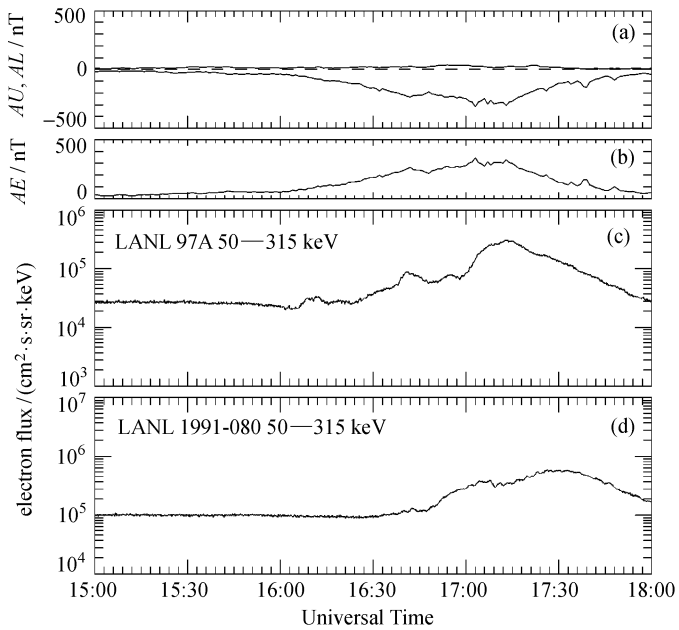


Figure 3 Auroral electrojet AU, AL (a) and AE (b) index, electron flux of 50–315 keV at geosynchronous orbit recorded by LANL 97A (c) and 1991-080 (d) during the interval of 15:00 UT–18:00 UT on 27 October 2004.

corded by Urumqi station in the night side has also presented Pi2 pulsation and a mid-latitude positive magnetic bay at about 15:52 UT, so that the auroral electrojet burst is also correlated with a substorm.

In both cases above, it is demonstrated that though AL dominant auroral electrojet burst is not well consistent with a typical substorm in the characteristic of aurora electrojet, the rest features of substorm are existent, including injection of geosynchronous orbital particles, Pi2 pulsation at low- and mid-latitude *etc.* Accordingly, the AL dominant auroral electrojet burst is also correlated with a substorm.

2.3 Auroral Electrojet Burst of AU Dominance

Here's another kind of auroral electrojet burst event contrary to the two cases on February 5 and October 27. During this kind of auroral electrojet burst, AU was dominant and AL was kept at low level. On January 17, 2004, an auroral electrojet burst occurred between two substorms (see Figure 4). In this event, AE began to grow at 20:08 UT and reached the maximum peak of 421 nT at 20:12 UT. AU index reached the maximum 395 nT at 20:14 UT, while AL was sustained at relatively low level, therefore this aurora electrojet burst was dominated by AU electrojet burst. The LANL recorder has shown that energetic electron flux in this event was unchanging, which indicates no particles injection phenomena happened.

During the interval of 06:00 UT–07:00 UT on December 30, 2004, another AU dominated auroral electrojet burst has happened (see Figure 5). In this event, AE began to grow at 06:22 UT and reached the maximum 802 nT at 06:29 UT. AU reached the maximum 691 nT at 06:29 UT while AL was sustained at a relatively low level. Therefore, this auroral electrojet burst is mainly induced by AU electrojet burst. Distinguished from the AU dominant electrojet burst on January 17, in this event, the geosynchronous satellite LANL has recorded high energetic electron flux growth during time interval of 07:22 UT–06:22 UT, which means that there existed geosynchronous orbital particles injection similar to substorm event, and the two night side mid- and high latitude stations of DAWSON (64°N, 220°E) and Victoria (48.6°N, 236.6°E) in Canada have recorded Pi2 geomagnetic pulsation. Therefore, this aurora electrojet burst is also correlated with a substorm.

3 Conclusions and Discussions

In this paper, we have analyzed the earth auroral ele-

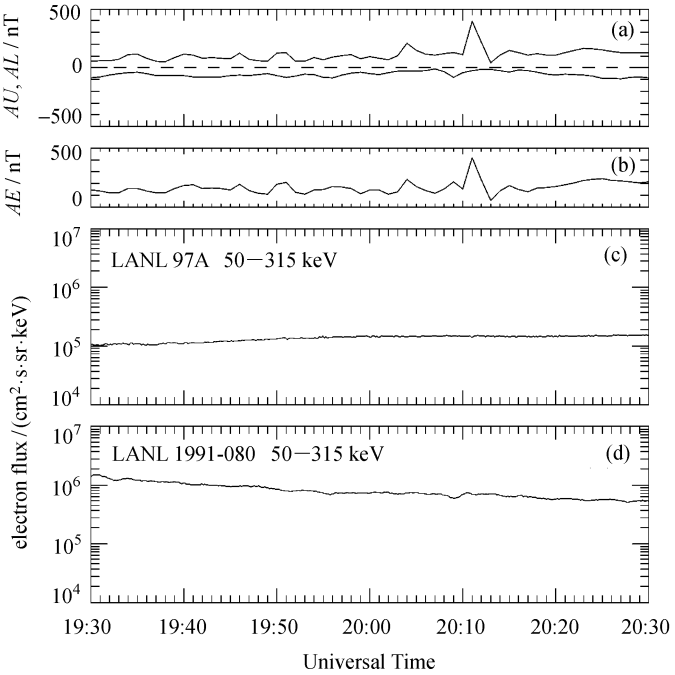


Figure 4 Auroral electrojet AU, AL (a) and AE (b) index, electron flux of 50–315 keV at geosynchronous orbit recorded by LANL 97A (c) and 1991-080 (d) during the interval of 19:30 UT–20:30 UT on 17 January 2004.

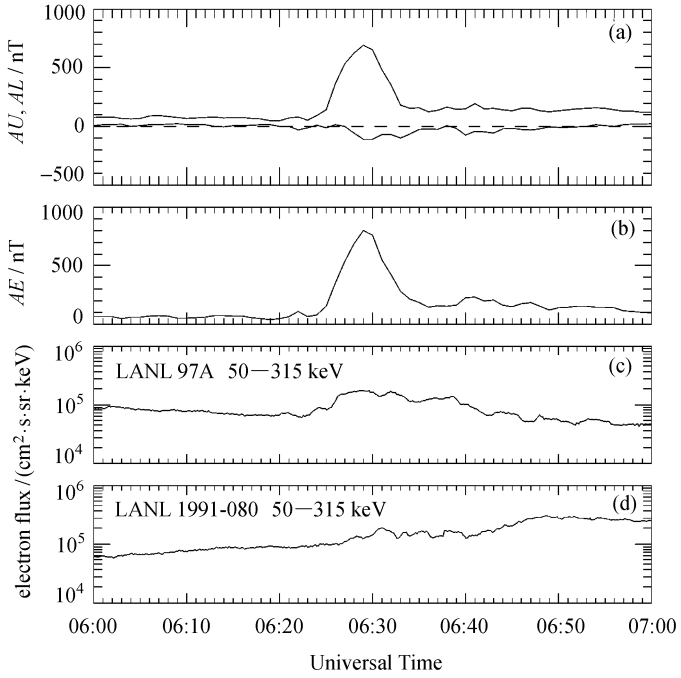


Figure 5 Auroral electrojet AU, AL (a) and AE (b) index, electron flux of 50–315 keV at geosynchronous orbit recorded by LANL 97A (c) and 1990-095 (d) during the interval of 06:00 UT–07:00 UT on 30 December 2004.

ctrojet bursts using the index of AE, AU and AL, the ground geomagnetic detection data and energetic particles data recorded by the geosynchronous orbital satellite as well. Investigation results showed that the auroral electrojet bursts could be divided into three types. In the first type, the eastward electrojet and westward electrojet bursted and disappeared simultaneously. These auroral electrojet bursts all have the accompaniment of geosynchronous orbital energetic particles injection as well as the Pi2 geomagnetic pulsation, which belonged to typical substorm events. The second type is AL dominant electrojet burst with AU index unchanging. These auroral electrojet bursts are also accompanied with geosynchronous orbital energetic particles injection and the ground Pi2 geomagnetic pulsation, which could also be regarded as substorm events. The third type is AU dominant electrojet burst with AL electrojet unchanging. Of this last type of aurora bursts, some have been followed by geosynchronous orbital energetic particles injection and the Pi2 geomagnetic pulsation and may be deemed as substorm events, while some have no accompaniment of geosynchronous orbital energetic particles injection and Pi2 geomagnetic pulsation, which are considered irrelative with substorm events.

From these analyses, it can be seen that though most of the auroral electrojet bursts are correlated with substorm events, there're still some auroral electrojet bursts which are unconcerned with substorm and existent primarily in the AU dominant auroral electrojet bursts. The AU electrojet burst mechanisms are correlated with not only substorm, but also other mechanisms irrelative with DP-1 current system, *e.g.*, abrupt enhancement of convection in magnetosphere and mutation of solar wind condition *etc.*

AE index of auroral electrojet is an important parameter for monitoring, predicting and studying substorms. Although there are other phenomena associated with substorms, such as auroral burst, geosynchronous orbital particles injection *etc.*, AE index from ground-based detecting is undoubtedly the most convenient and reliable substorm parameter. Results in this paper are significantly referential to explore and detect substorm by utilizing AE index of auroral electrojet.

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Brief Introduction to State Key Laboratory of Space Weather

The State Key Laboratory of Space Weather was founded in 2006, which is the first state key laboratory approved by the Ministry of Science and Technology in the field of space physics in China. There are currently about 60 research staffs in the laboratory, which includes two academicians of the CAS (Chinese Academy of Sciences), six PIs from the One Hundred Talent Program of the CAS, and four winners of National Science Fund for Distinguished Young Scholars. It also has a space weather team of NNSFC (Natural National Science Foundation of China), supported by the Science Fund for Creative Research Groups. The laboratory owns Chinese Center of CLUSTER Database, Double Star Program (DSP) Data Center, DSP Scientific Operation Center, High Performance Computing System, and the first Radiation Test and Calibration Center in China.

The laboratory is dedicated to the adverse space weather and its influence on human activities. The main goals include: to investigate the fundamental space weather processes in the solar-terrestrial space; to establish the physics-based realistic space weather forecast methods and models; to explore the new space mission concepts and develop new observational techniques.

During the past few years, the laboratory has led two major science projects, five key science projects and one Creative Research Group from NNSFC. The laboratory has initiated the first science satellite Program—"Double Star Exploration Project (DSP)", which PI is Academician Liu Zhenxing. The evaluation of this project ranked "Excellent" in 2008. The laboratory also proposed the ground-based space weather monitoring chain ("Meridian Project") and has finished the proposal, the feasibility study report and the preliminary design report. It is the first step of the construction of Chinese ground-based space environment monitoring network. The laboratory also plays an important role in promoting the national space plans such as "KuaFu Project" and "China-Russia Joint Mars Exploration Plan". All of these work greatly put forward the development of Space Science in China. As a leading group in space weather of China, the laboratory has obtained lots of original research achievements, and is becoming one of the first-class space weather research centers in the world.