Convection vortices in pre- and post-midnight sector during magnetospheric substorms

J. Liang, G. Sofko, and H. Frey

Abstract: In this study the nightside ionospheric plasma convection pattern during two substorm events is investigated from global SuperDARN observations. We find that, a postmidnight anticlockwise convection vortex (PoACV) usually emerges at latitudes higher than the auroral brightening region after the substorm expansion phase onset. Meanwhile, an east-to-west flow reversal region wrapping around the intensified auroras extends into the postmidnight sector. A premidnight clockwise vortex is gradually attenuated or even absent, during the substorm expansion, The substorm current system inferred from the relative positions of the PoACV and the auroral brightening region is in general northeast-southwest aligned, implying a mixture of a meridional current system (MCS) and a zonal system associated with the substorm current wedge (SCW).

Key words: Substorm expansion phase, plasma convection, meridional current system.

1. Introduction

High-latitude ionospheric plasma convection flows usually undergo dramatic changes and display fundamentally different features during successive stages of a magnetospheric substorm. By using the AMIE algorithm, [8] (referred to as KY94 hereafter) proposed that a new pair of convection vortices appears in the nightside during a substorm expansion phase (EP) in addition to the pre-existing global 2-cell pattern. The new pair of vortices consists of a higher-latitude anticlockwise vortex located mainly in the postmidnight sector, and a lower-latitude clockwise vortex extending from the premidnight to the postmidnight sector. [9] suggested that these vortices are signatures of the unloading component of the auroral electrojet associated with substorm expansion, as opposed to the solar wind directly driven component. One of the most important features of the KY94 model is that the current pattern associated with the two new vortices is characterized by a meridional current system (MCS) as opposed to the more azimuthally-aligned (zonal) system usually related to the substorm current wedge (SCW) geometry [14]. [1] suggested that the substorm current system was dominated by the MCS form. [13] proposed a non-MHD mechanism driving the MCS. For a small substorm event, [11] found that an enhancement of nightside convection and the appearance of a small postmidnight anticlockwise vortex immediately after the first pseudobreakup were signatures of the tail unloading process. In this paper we will present two events to illustrate the dynamic change of ionospheric convection pattern around the midnight sector associated during the substorm EP. In particular, we investigate the different evolution of convection vortices in the pre- and post-midnight sectors after the substorm onset. Possible generation mechanisms of the convection vortices and the associated current system will be discussed. sent two events to illustrate the dynamic change of ionospheric convection pattern around the midnight sector associated during the substorm EP. In particular, we investigate the different evolution of convection vortices in the pre- and post-midnight sectors after the substorm onset. Possible generation mechanisms of the convection vortices and the associated current system will be discussed.

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2. Observations

We will use the global potential map procedure [15] to obtain the SuperDARN convection maps. Global optical auroral observations are taken from the IMAGE FUV/WIC imager [5].

2.1. February 22, 2001 event

The first interval considered is from 0830-0842 UT on February 22, 2001. The auroral breakup observed by the IMAGE FUV camera was at 0833 UT. This onset time was supported by ground-based magnetometer and also geosynchronous observations (see [12]). A series of the ionospheric plasma convection maps based on SuperDARN radar measurements taken from 0830 UT to 0842 UT are presented in Figure 1. From 0830 to 0832 UT, an interval which marked the end of the substorm growth phase, the large-scale convection pattern in the morning sector was a single convection cell centered at 4.2 MLT. In the postmidnight sector from 0-3 MLT, the flows were dominantly equatorward. At lower latitudes (70 MLAT) the flows was in general southeastward and rather weak in magnitude. The postmidnight convection pattern changed substantially from 0832 to 0834 UT, during which time the substorm auroral breakup region was seen in the evening sector around 20.5-22 MLT. Note that the postmidnight flows at this stage started to show evidence of zonal shear; the flows were dominantly westward above 72 MLAT but almost purely eastward at lower latitude. The zonal flow shear continued to develop after the onset, and the eastward auroral flows at about 70 MLAT were considerably enhanced as seen from the next two frames from 0834 to 0838 UT. Finally, at 0838-0840 UT, about 6 minutes after the EP onset, a well-defined anticlockwise convection vortex formed. It is centered at 1.2 MLT and 72.5 MLAT in the postmidnight sector, while the preexisting dawn cell is still visible in the early morning sector. At the same time, in the vicinity of the region of brightest auroral emissions at 22.5 MLT, the flows were diverted around the zone of intensified aurora, eastward at higher latitudes and westward at lower latitudes, forming an intruding part of the original dusk cell. This intruding flow reversal region was found to extend into the postmidnight sector. Despite the small number of data points at lower auroral latitudes, there is still evidence that an east-to-west flow reversal at least at about 67 MLAT and 1.2 MLT. Unlike the evening sector, the flow reversal region in the postmidnight sector did not correspond to intense auroral intensification, probably because conditions were unfavorable for the onset of the magnetospheric-ionospheric feedback instability which would have led to auroral brightening [2]. It is important to notice that, the intruding flow reversal region shown in Figure 5e could be equivalently viewed as the lower unloading cell in KY94 model (see Figure 1) that is attached to a background dusk cell seen in previous frames. Thus the overall convection pattern in Figure 5e is consistent with the two unloading cells postulated by KY94. Those convection features persisted during the interval 0840-0842 UT. In this event the focus of the PoACV was 2-3 higher in latitude than and 2.5-3 h MLT to the east of the brightest auroral region around 22.5 MLT (There was also bright aurora around 20 MLT in the dusk sector). During the whole event, there is no evidence of the existence of a premidnight clockwise vortex other than the persisting dusk cell.

2.2. December 15, 2001 event

The event was studied in [10] for other research purpose. The substorm EP onset time was determined from the IMAGE FUV/WIC observation, ground magnetometer and LANL geosynchronous observation as 0915 UT. Figure 2 gives a series global convection maps for this event. A well-defined clockwise vortex centered at 750 MLAT, 22 MLT can be identified as early as 0858-0900 UT, 16 minutes prior to the substorm EP onset. Such premidnight clockwise vortex persisted till the end of the growth phase (0912-0914 UT). At 0914-0916 UT, the interval marking the substorm auroral breakup, the premidnight clockwise vortex was significantly enhanced. So far there was not any clear signature of a PoACV, and the convection in postmidnight sector was overall weak in magnitude. At the interval 0918-0920 UT, 4 minutes after the onset, a clear identifiable PoACV centered at 730 MLAT, 2.8 MLT appeared, while the preexisting premidnight vortex clearly attenuated. At 0922-0924 UT, though there was an enhancement of westward flows near the equatorward edge of brightened auroras, which is identified as sub-auroral polarization stream (SAPS) by [10], the flow magnitude directly associated with the premidnight clockwise vortex significantly decreased compared to the onset frame 0914-0916 UT. At 0924-0926 UT, such premidnight vortex became deformed and no longer clearly identifiable. Similar to the first event, there was continuous eastward flow enhancements at the equatorward part of the PoACV in the postmidnight sector, and we notice that, an east-to-west flow reversal, as an intruding part of the dusk convection cell, extend progressively toward postmidnight after substorm onset. At 0924-0926 UT, evidences of such east-to-west flow reversal can be seen as far as 640 MLAT, 4 MLT.

3. Discussion

We have studied in detail the evolution of convection vortices in the nightside ionosphere during the substorm EP for two events. In both events we have seen that a postmidnight anticlockwise convection vortex emerge a few minutes after the substorm onset. The foci of the anticlockwise vortices were located at higher latitudes than, and east of, the brightest auroral region. The anticlockwise cell (upward vorticity) implies downward FACs, while the bright optical aurora is usually associated with the precipitating electrons and thus upward FACs. The inferred substorm closure current system showed northeast-to-southwest alignment, and therefore can be resolved into a meridional component and a zonal component, with the latter corresponding to the traditional SCW configuration. Another consistent feature is an east-to west flow reversal region at lower latitudes. It represents a transition from the westward electrojet (eastward flows) in the auroral region to the SAPS-like westward flows near and/or south of the equatorward border of the auroral oval [4][10]. This flow reversal region progressively expands into the postmidnight sector during the substorm EP, which is consistent with the observations that SAPS may extend well into the postmidnight sector during strongly magnetically disturbed periods [7][4]. One of the consequences of this postmidnight intrusion of the flow reversal region is that it becomes closer in longitude to the PoACV located at higher latitude. For example, at 0838-0840 UT in the first event, the east-to-west flow reversal region was visible up to 1.2 MLT, which is roughly the same longitude as the focus of the PoACV. Although the most intense upward FACs in this event are undoubtedly located in the brightest auroral region in the evening sector well to the west of the PoACV, a smaller portion of upward FACs also occurred in the flow reversal region at 67 MLAT in the postmidnight sector. This portion would form a primarily MCS geometry with the PoACV at higher latitude. This result again reveals the coexistence of the meridional and zonal components of the substorm current system. In the first event (and also in all events in [11][12]), there was no signature of a premidnight clockwise vortex other than the dusk cell during the whole event interval. In the second event, however, a premidnight clockwise vortex was present the late growth phase. This premidnight vortex was significantly intensified right at the EP onset frame, but tended to attenuate and deform afterwards. Together with the postmidnight anticlockwise vortex that appeared 4 minutes after the substorm EP onset, the pair of vortices consists the twin-vortex convection system generated by nightside reconnection [3]. The foci of the twin-vortex flows are located at each end of the nightside merging gap. [6] performed an event study to demonstrate the excitation of nightside twin-vortex flow during a substorm EP; the focus of the postmidnight vortex was at 73 MLAT and 1 MLT, which is quite comparable to our results. The sudden enhancement of the premidnight clockwise vortex right at the substorm onset time seems to be consistent with the reconnection-driven scenario. However, the observational fact that such premidnight vortex gradually attenuated and deformed after the substorm onset is not easily explained by the above nightside reconnection-driven mechanism. Also, the strong enhancement of eastward flows at the equatorward part of the PoACV implies the presence of other dynamics associated with the substorm EP process. We believe the enhanced eastward flows at auroral latitudes are likely directly related to the substorm-associated process in the central plasma sheet and the dynamo of MCS. The underlying mechanism is not fully understood. [13] proposed a non-MHD mechanism for the earthward magnetospheric electric field which drives the eastward plasma convection and the MCS. [1] suggested a MHD dynamo for the MCS. No matter the actual process driving the MCS, the combination of such process and the nightside reconnection may explain the observed convection feature during substorm EP. If one compares the vorticities expected from the reconnection-driven process and from the MCS configuration (Figure 3a), it is clear that, in the premidnight sector the high-latitude vortices generated by the above two mechanisms have different rotational senses and tend to cancel each other, leading to an attenuation or even absence of the premidngiht vortex, while in the postmidnight sector they have the same rotational sense and reinforce each other to form a strong PoACV. The remnant part of the evening reconnection cell concatenates with the lower-latitude MCS cell to form a unified flow region with clockwise convection reversal (Figure 3b).

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