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Interactive
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Interactive comment on "A new scenario applying traffic flow analogy to poleward expansion of auroras" *by* Osuke Saka

O. Saka

saka.o@nifty.com

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Our replies to Referee #2 are summarized as follows.

The first 10 min interval of Pi2 onset is a transitional state of the substorm dominated by MHD processes associated with earthward flow and its bifurcation [Saka et al., JASTP, 72,1100-1109, 2010]. In this interval, a collapse of dipolarized geomagnetic field configurations started to return to the original field line configurations characterized by the potential fields. The poleward expansion of auroras occurred in the first one-minute-interval of Pi2 onset (initial pulse of Pi2). [Saka et al., JASTP, 80, 285-295, 2012]. During the subsequent Pi2 pulses following the initial pulse, an auroral surge propagating eastward or westward at the poleward boundary of the auroral zone was

observed in all-sky images that were interpreted as an auroral manifestation of flow bifurcation of fast earthward flows (BBFs) [Saka et al., JASTP, 80, 285-295, 2012].

It is supposed that auroral signatures associated with the BBFs could be found in low latitudes because the inclination angle of field lines in the equatorial plane attained minimum values at the Pi2 onset (see Fig1 attached to this reply, reproduced from [Saka et al., JASTP, 2010]), that were caused by the continuous inflows towards the equatorial plane in the preonset intervals [Saka and Hayashi, JASTP, 164, 235-242, 2017]. This means that an activation of the preonset auroras can be regarded as an auroral manifestation of BBFs. The activation was followed by auroral beading and dawn-dusk stretching of the flux tubes. In contrast, an evolution of N-S auroras (streamers) from the poleward auroral boundary occurred in association with Pc4 pulsations and, at least at the geosynchronous orbit, no inflows were observed [Saka et al., JASTP, 145, 114-124, 2016].

At the poleward boundary of auroral zone, fast aurora surge correlating to Pi2 pulse as described above was observed in 66 – 74 ILat. Velocity of the surge, 12 - 30km/s at 100 km in altitudes, corresponds to azimuth flows of the order of 190 – 480 km/s at L=8.5 (70 ILat). It is supposed that these azimuthal flows may be an energy source exciting Alfven waves in the poleward boundary of auroral zone. Steady state parallel ion flows created by the ion acoustic waves along the compressed collisional ionosphere carry ionospheric ions towards the topside ionosphere as depicted in Figure 4B. The upward ion flux carried by the flow varied from $5.9 \times 10^{12} m^{-2} s^{-1}$ at an altitude of 400km to $8.2 \times 10^{13} m^{-2} s^{-1}$ at 800km. This means that the parallel flows evacuated the accumulated ions in 250 s (4.2 min) at 750 km, while ions at 450 km were slowly evacuated to the higher altitudes in 3300 s (55 min). Quick evacuation of ions in higher altitudes may create ion holes in the topside ionosphere. These ion holes in the topside ionosphere are potential candidates for double layers, an inverted-V potential structure [Hudson et al., JGR, 88, 916-926, 1983]. Ion acoustic waves related to auroral arcs were observed in the EISCAT radar echoes as naturally enhanced ion acoustic spec-

tral shoulders [Wahlund et al., JGR, 97, 3019-3037, 1992]. In the present scenario, poleward boundary aurora surge is Alfvenic in nature and auroras associated with the ionospheric compression are of the inverted-V type.

In nightside magnetosphere, Pi2 pulsations are regarded as a repeating flow bifurcation with a time constant of minute, or flow diversion of BBF substructures [Saka et al., JASTP, 72,1100-1109, 2010]. If BBF substructures are related somewhat to the substorm cadence, Pi2 pulsations are geomagnetic manifestation of mid-tail reconnection repeated with the time constant of one minute.

In the initial pulse of Pi2, flux tubes stretching in tailward directions switched to dawn-dusk directions through MHD processes. The dawn-dusk stretching in the initial pulse was not localized but expanded in longitudes over 19 to 04 LT [Saka et al., JASTP, 62, 17-30, 2000]. A possible candidate for the MHD processes is an excitation of slow MHD waves [Saka and Hayashi, JASTP, 164, 235-242, 2017]. This switching from tailward to dawn-dusk directions disrupts the cross-tail currents and may produce convection surge and associated westward electric fields in the midnight sector [Saka et al., Ann Geophys., 32, 1011-1023, 2014]. The convection surge may not repeat in the same longitudes. This means that auroral expansion was observed once in the initial pulse of Pi2 pulsation.

We proposed the traffic flow analogy to explain the poleward expansion of auroras because the flux-density curve (Figure 3A) for the traffic flow was applicable to the ionospheric case. A similar case may be found in "flow braking in near-Earth tail" [Shiokawa et al., GRL, 24, 1179-1182, 1997] if an excess pileup of the pressures was suppressed by the ion flow itself as expressed in the advective term in the equation of motion. This may minimize the velocity of the ion flows at the pressure peak analogous to a tailback of cars in traffic flows.

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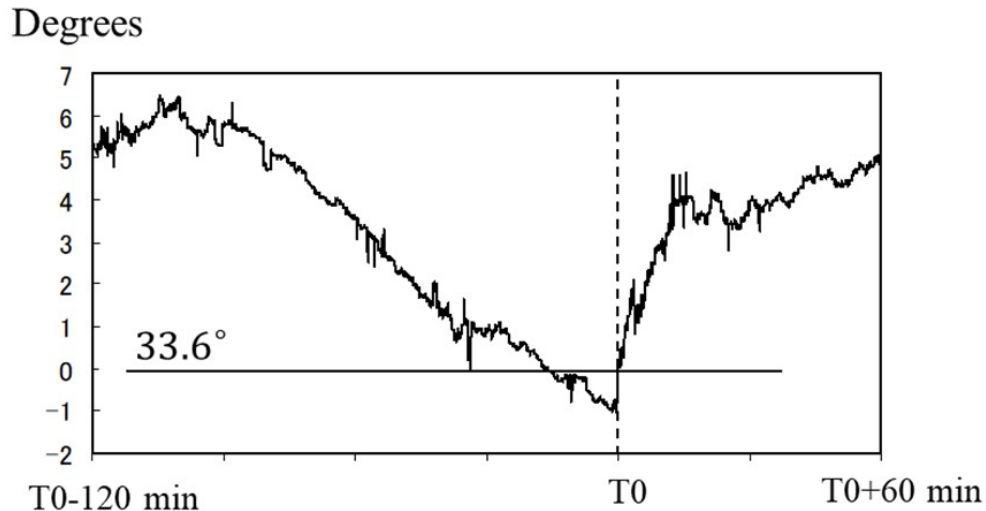
Mean inclination angles (G5)

Fig. 1. Mean inclination angle of geomagnetic fields at geosynchronous orbit (Goes5) from T0 -120 min to T0 +60 min, where T0 denotes Pi2 onset.