"Physics of Auroral Phenomena", Proc. XLI Annual Seminar, Apatity, pp. 118-121, 2018

Polar Geophysical Institute

DOI: 10.25702/KSC.2588-0039.2018.41.118-121

ION UPWARD FLOWS IN THE SUBAURORAL POLARISATION JET

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Abstract. Polarisation Jet, or SAID (SubAuroral Ion Drift), is a narrow band of fast westward convection which can appear during geomagnetic substorms in the subauroral zone approximately along the nightside plasmapause. It causes strong heating of subauroral plasma due to collisions and fast plasma outflows. It results at F-region altitudes an upward or downward plasma motions, a narrow drop in density, or "trough in the trough", changes in ion composition, an electron temperature peak, weak SAR-arc, density inhomogenieties and other effects. Data on ion drifts and field-aligned ion outflows from Kosmos-184 and DE-2 satellites at ionospheric altitudes are analysed. Model calculation have shown that bi-Maxwellian ion distributions resulting from perpendicular ion heating in regions where the magnetic field is inclined to the satellite velocity vector, can produce vertically asymmetric fluxes in a driftmeters frame which mimic fast field-aligned ion flows. It is shown that in many cases the data within the Polarisation Jet are consistent with the contribution of the perpendicular ion heating as an additional cause of the observed fast convection.

Introduction

The Polarisation Jet is a subauroral narrow supersonic westward stream of ionospheric ions at, or close to, the equatorial edge of the convection during a storm. It was first measured in 1967 from the Kosmos-184 near-Earth satellite and described in [*Galperin et al.*, 1973, 1974]. Later it was rediscovered by [*Smiddy et al*., 1977] and named SAID (SubAuroral Ion Drift) by [*Spiro et al*., 1978]. Then it was studied experimentally in many papers from satellites, incoherent and coherent radars and from ground-based ionograms and ionospheric drift data.

We retain here the original name of the phenomenon, the Polarisation Jet (PJ) introduced in [*Galperin et al*., 1973, 1974]. It is distinct from other types of subauroral ion drifts, such as due to substorm-enhanced neutral winds, effects of gravity wave dissipation, substorm electric field penetrations to lower latitudes, all of which may be observed at subauroral latitudes.

It was found that PJ occurs at the nightside in the poleward part of the ionospheric main trough. It coincides, at the non-sunlit F-region, with a deep narrow drop in the electron density. This ionospheric feature was called the "trough in the trough" in [*Filippov et al*., 1984]. After creation of the "trough in the trough", it can persist for some time even without the rapid PJ flow (i.e. after the decay of the driving electric field) thus contributing to the "fossil trough".

A narrow peak of the electron temperature, Te, corresponds to this drop of electron density, Ne. It results in a band of enhanced 630 nm emission excited by the hot tail of thermal electrons; this optical feature is often called the SubAuroral Red Arc (SAR-arc). Usually a SAR-arc associated with a PJ, and "trough in the trough", has the red line intensity of less than 1 kR [*Alexeyev et al*., 1991; *Foster et al*., 1994]. Strong westward drifting F-region inhomogeneities accompany the PJ and produce specific oblique spread echoes on subauroral ionograms (see, [*Filippov et al*., 1984]). Thus the ionosondes can be used for the ground-based identification and location of the PJ. We note that such inhomogenieties can produce effective perpendicular ion heating by electrostatic waves and, when collisions are slow or absent, an ion conic formation.

Instruments and Data Sets

The Kosmos-184 satellite was launched on October 30, 1967, the orbit was circular at 630 km with 83^{o} inclination. The satellite was oriented along the satellite velocity vector. The data were received till the end of November, 1967.

The Kosmos-184 instrument was oriented along the satellite velocity vector. It consisted of four identical narrow field Faraday cups, forming a horizontal pair and a vertical one, with an angle 18^{o} between the axes in each pair. The difference current within each pair was registered as a measure of the respective ion drift transversal velocity component, Vcross in the horizontal plane, and Vvert in the vertical plane. The telemetry read the measured parameters, Vcross, Vvert and Ni, once in 4 seconds and an orbit memory was available during late October-November 1967. The data treatment procedures are described in [*Galperin et al*., 1973].

The DE-2 drift-meter instrument consists of the Faraday cup with the current-collecting plate rectangularly split to four parts. Difference currents in pairs and total ion current are measured which allows to measure Vcross, Vvert, Ni. Using the retarding potential sweep it is also possible to evaluate partial concentrations of main ion components, ion temperatures and by their relative positions, the ion drift velocity component along the satellite velocity and the satellite's potential in respect to plasma.

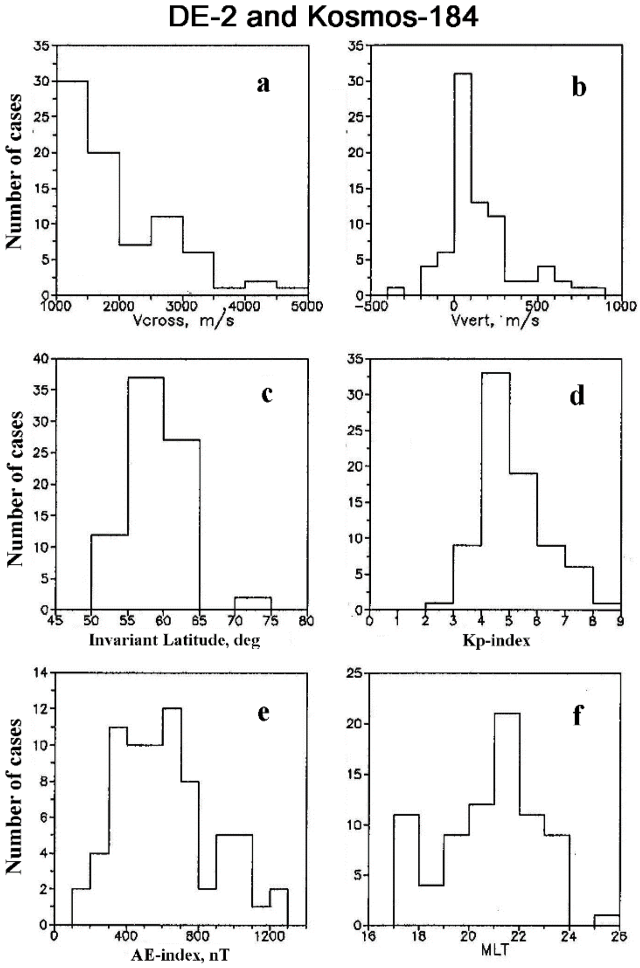

Figure 1. The statistical distributions of the PJ cases.

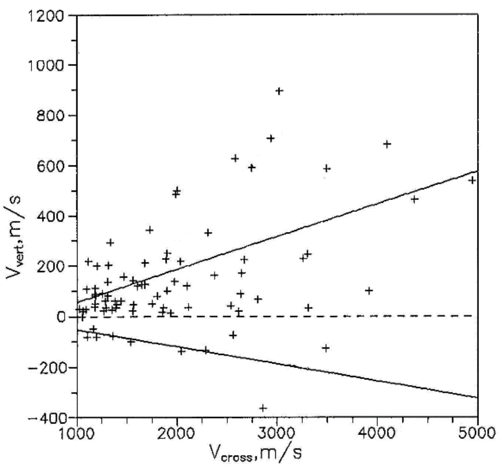

Figure 2. The mutual dependence of vertical and horizontal velocities in the PJ.

The detailed comparisons of such data with the independently measured electric field data from the same satellite DE-2 performed by [*Hanson et al.*, 1993] showed an excellent agreement to the precision of about 1 mV/m or better for the latitudes under consideration here.

Statistics on Polarisation Jets

We take as a working definition of a PJ crossing the westward drift velocity Vcross threshold value of 1 km/s in order to surpass most of the effects of wind velocities in subauroral ionosphere at disturbed times. From the existing experience the PJ crossings are located at, or close to, the equatorial boundary of the large scale convection at the nightside. The data set considered in this study covers 92 cases of PJ crossings at altitudes from the DE-2 perigee ~300 km till about 950 km, collected during 1981-1982 and 6 cases from the Kosmos-184, at altitude 630 km, collected in 1967.

The statistical distributions of the PJ cases considered are presented in Fig. 1. They show that the interval of the PJ registration was mainly in the premidnight sector 19.00-24.00 MLT; in most cases (about 75 percent both), the Vcross and Vvert were in the range from -3000 to -1000 m/s and from -200 to 400 m/s, respectively; the invariant latitudes of the PJ registration mainly were at 55 - 65 degrees (about 80 percent); and the PJ was observed during moderately disturbed periods of the geomagnetic activity.

Fig. 2 shows the mutual dependence of vertical and horizontal velocities in the PJ.

Fig. 3 shows that the average Vvert values within PJ events are altitude dependent. It shows that while at high ionospheric altitudes the field-aligned flows observed are nearly always upward, at the altitudes around the F-maximum and below both upward and downward flows are observed. The field-aligned flow velocities, especially upward velocities, can reach very high values (up to 0.5-2 km/s) at low altitudes where collisions would not allow sonic and supersonic MHD flows. These exceptionally high outflow velocities occur only when Vcross > 2 km/s.

To demonstrate the problem for interpretation they present, we plotted a velocity-altitude dependence from one of our MHD calculations with the TUBE model [*Grigoriev*, 1991] of the Vvert on the Fig. 3 together with two other sample model calculations published in literature by [*Sellek et al.*, 1991; *Korosmezey et al.*, 1992]. These model results correspond to different numerical schemes and particular conditions. However, they consistently show that only subsonic field-aligned flows (ion diffusion downward) are possible within the MHD models applied.

Ground-based data

According to the data of vertical sounding and Doppler measurements at Yakutsk station in 2006-2012 the 44 events of PJ were considered. The event statistics showed in Fig. 4. Here, 0 hour in the abscissa axis is the time of the horizontal velocity maximum in PJ event. It can be seen that the vertical velocities in the PJ event obtained for all events have two peaks, approximately 1 hour before the maximum of the horizontal velocities and 1 hour after. The nature of this behavior of vertical velocities can be explained as follows: the first peak appears due to Joule heating; further, at a maximum of the horizontal velocity, the neutrals are already involved in the motion and the velocity difference is less, consequently, the heating is less. After a maximum of horizontal velocity, the ions are braked and the neutrals move according to the old velocity, and the difference in velocities again increases and, as a result, the heating and vertical upflow increase again.

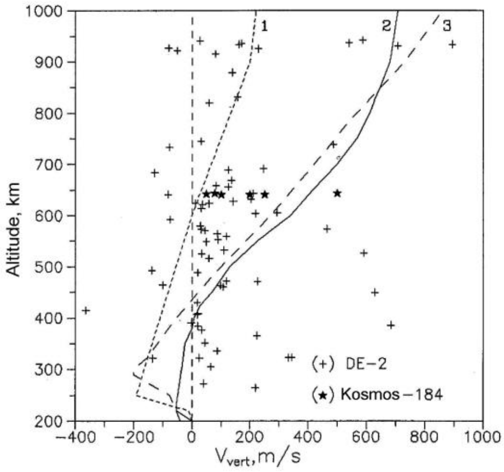

Figure 3. Distribution of vertical velocities in the PJ from the altitude of their measurement on satellites. Model calculations by [*Sellek et al.*, 1991] (***1***), [*Korosmezey et al.*, 1992] (***2***) and [*Grigoriev*, 1991] (***3***).

Mathematical modeling of the Polarization Jet influence at ionospheric heights

In this study we use a mathematical model of the high-latitude ionosphere in Euler variables which taking into account the discrepancy between geographic and geomagnetic poles [*Gololobov et al.*, 2014].

The basis for the calculation: Solar activity F10.7 = 150; Geomagnetic activity Kp ≤ 3; Vernal equinox; Electric field E = 50 mV/m, or Horizontal velocity = 1000 m/s; Vertical velocity = 100 m/s; Latitudinal Width = 4 degrees; 12-24 Local Time.

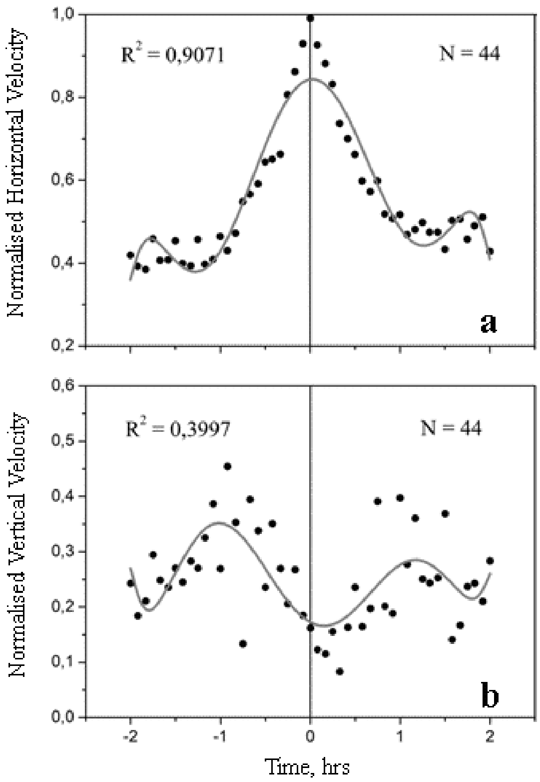

Figure 4. Horizontal and vertical plasma velocities within PJ band. The *thick curves* are the approximating lines, *the points* - normalized velocity values.

Summary

- DE-2 and Kosmos-184 satellites data shows that heat flux in the PJ events is generated at the ionospheric altitudes due to collisions and propagates both upward, in the magnetosphere, and downward, to the lower ionosphere. The enhanced electron temperature most likely leads to a SAR-arc formation.
- It is found that the vertical upflows cannot coincide with the maximum of the horizontal velocity in the Polarization Jet event. Vertical velocities in the PJ event have two peaks, approximately 1 hour before the maximum of the horizontal velocities and 1 hour after.
- Model calculations have shown that the PJ affects the structure of the ionosphere. At horizontal velocities (v = 1000 m/s), a sharp drop in the electron density of the F layer is observed at the interval where the electric field is turned on. At vertical velocities (v = 100 m/s), an electron density and height are increases in F layer maximum at the interval where the electric field is turned on.

Acknowlegments. This work is supported by Project II.16.2.1 (registration number AAAA-A17-117021450059-3) and is partially supported by the Russian Foundation for Basic Research (Project N18-45-140037).

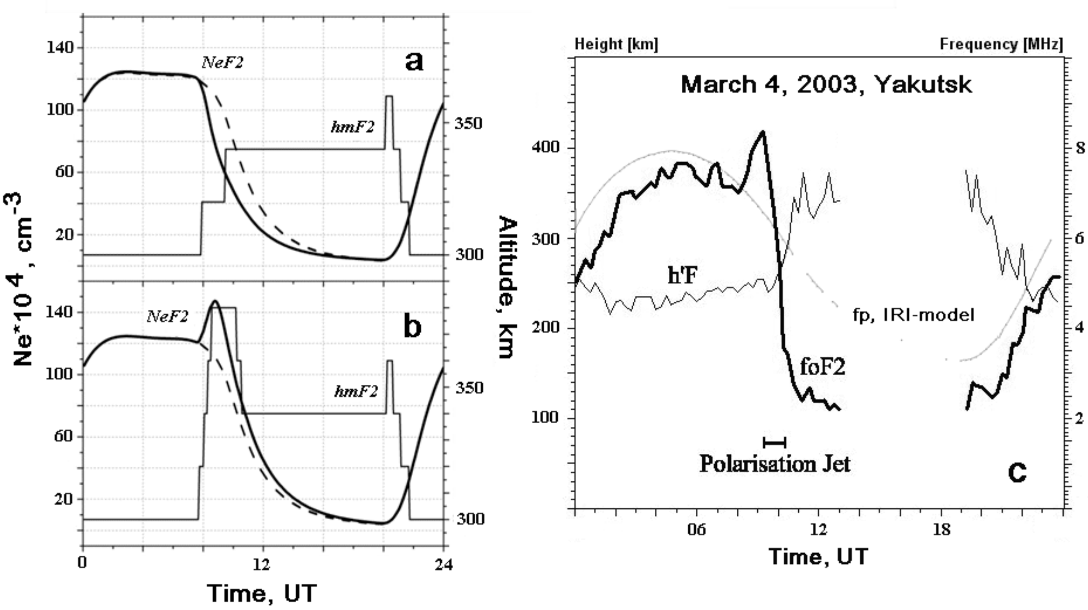

Figure 5. Daily variations of electron concentration at the maximum height of an F2 region by model calculations: ***a*** - taking into account the horizontal velocity only; ***b*** - taking into account the vertical velocity only; *Dashed line* is without taking into account the PJ velocities. ***c*** - the diurnal variation in the parameters of *fo*F2 (*thick line*) and h'F (*thin line*) on March 4, 2003, Yakutsk.

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