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Optical and radar observations of small-scale polar cap auroral structures

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ABSTRACT

We present ground-based auroral observations from Resolute Bay, Nunavut, Canada (74.73°N, 94.9°W) during January 2011. Two electron-multiplying CCD (EMCCD) imagers were operated at 31 frames per second. One was equipped with an all-sky field of view (FOV) lens and the other with a narrow (19°) FOV lens, centered on the geographic zenith (0° Az., 90° El.), a few degrees away from magnetic zenith (315° Az., 88° El.). The Resolute Incoherent Scatter Radar (RISR) was operating in a mode that enabled common-volume observations with the imagers. Being well inside the polar cap, the magnetic field at Resolute Bay is considered 'open' and connects to the lobes of the magnetotail. However, there is no clear consensus on whether polar cap aurorae occur on open or closed field lines. The electron acceleration is likely driven by direct solar wind processes, distant tail lobe processes or plasma sheet processes. One possible mechanism for accelerating the precipitating electrons is the parallel electric field of inertial Alfvén waves. The dynamic nature of the small-scale auroral features, observed on several nights, and the altitude extent of the ionization observed with RISR provide support for this hypothesis.

1. Introduction and background

Polar cap aurorae have been observed for decades, with the first reported observations occurring in the early 20th century (Mawson and Chree, 1925). During the international geophysical year of 1958–1959 the study of polar cap aurora increased significantly due to the advent of the all-sky camera (Davis, 1960). The full history and recent state of polar cap auroral observations is summarized in the review by Zhu et al. (1997).

The statistical dependence of polar cap aurorae on the interplanetary magnetic field (IMF) is a subject of debate. Studies have been done using both ground-based and satellite data (Zhu et al., 1997). Ground-based imaging is better suited for the study of the fainter, smaller scale auroral arcs, while satellite instrumentation for observing the brighter, large scale aurora. There are likely multiple types of polar cap aurorae with varying levels of brightness and scale size and this may be why there have been disparities in reporting. A correlation between polar cap aurora and IMF B_y has been deduced from satellite optical observations. Imaging from the Defense Meteorological Satellite Program (DMSP) in visible wavelengths and Viking UV observations has shown that the polar cap aurora is preferentially seen in the morning sector for IMF B_y negative and the evening sector for IMF B_y positive (Gussenhoven, 1982; Elphinstone et al., 1990; Makita et al., 1991; Kullen et al., 2002). Ground-based studies have not yielded this particular correlation but instead one between the dawn-dusk motion of the auroral structures and the direction of the IMF B_y (Rairden and Mende, 1989; Valladares et al., 1994).

More recently, Cumnock et al. (2009) used a combination of polar UVI and DMSP electron data to examine the IMF dependence of large-scale polar cap auroral arcs, which show substructure in the particle signatures. They found a correlation between the occurrence of polar cap aurora and northward IMF followed by a change in IMF B_y. In addition, Kullen et al. (2002) found no IMF correlation between the less-common midnight and multiple arc events.

The ion and electron signatures of bright polar cap aurora are similar to those found in the auroral oval and therefore it is assumed that the bright polar cap auroral arcs also have a plasma sheet source population, consistent with a region of closed field lines extending up into the polar cap (Meng, 1981). There is still no clear consensus on whether all polar cap aurorae occur on open or closed field lines or if some occur on open and some on closed field lines. Conjugate satellite observations of polar cap arcs (Obara et al., 1988; Huang et al., 1989) have provided evidence that they occur on closed field lines. Bonnell et al. (1999) found, using data from the Fast Auroral SnapshoT (FAST) satellite, that the lobe reconnection model was consistent with

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the electrodynamics and temperatures of the precipitating electrons and ions, but not the presence of precipitating O^+, which was observed. The plasma sheet source model was consistent with the composition, but not the temperature of the observed precipitating electrons and ions.

It should be noted that these previous studies used satellite imagery to identify polar cap arcs, and were therefore selecting for large-scale and long-lived auroral features. The large-scale features are most often a northward IMF phenomenon. The high time-cadence ground-based imagers used in this study enabled the observation of small-scale and transient auroral structures that occur inside the polar cap, which show less correlation to IMF conditions.

2. Method

An observational campaign was conducted from Resolute Bay, Nunavut, Canada, at a geodetic location of 74.7°N, 94.9°W (82.5°N, 52.4°W geomagnetic) with local magnetic midnight occurring at approximately 07:45 UT. The optical data were recorded using two electron-multiplying CCD (EMCCD) imagers, both unfiltered, recording the white-light auroral emissions at 31 frames per second. One was equipped with an all-sky field of view (FOV) lens and the other with a narrow field of view (FOV) lens (19°). The spatial resolution is approximately 1.5 pixels per degree, or 800 m–1 km per pixel in the vicinity of the zenith for the all-sky imager and approximately 13 pixels per degree, or 100 m per pixel for the narrow field imager.

The campaign was conducted in early January, from the 7th to the 18th, in order to maximize the local time coverage of the potential auroral observations. The RISR radar operated nearly continuously during that time interval and auroral structures were observed in the optics on several nights when clear observing conditions existed.

3. Observations

The nights of 8 and 9 January 2011 had good observing conditions with few clouds and blowing snow. The resolute incoherent scatter radar (RISR) was running a long plulse (480 μs) raw data mode with multiple beam positions, including one up the geographic zenith (26.6° Az., 90.0° El.) which is very close to magnetic zenith (315° Az., 88° El.). The magnetic zenith is the best place to observe the altitude profiles of ionization resulting from auroral particle precipitation with the radar and also to distinguish the perpendicular widths of auroral structures observed in the images. If one looks off-zenith the altitude extent of the aurora cannot be distinguished from the horizontal extent.

3.1. 8 January 2011

Fig. 1 shows auroral images from both the all-sky (left) and narrowfield (right) imagers at 09:55 UT (top) and 09:56 UT (bottom), at 02:10 MLT and 02:11 MLT respectively. In these views, North is at the top and East is to the left. This particular auroral arc occurred in the midnight sector and was the brightest and the only one observed to be mostly North-South aligned during the campaign. It formed quickly, with an arc width in the E–W direction of approximately 10–20 km, and lasted for only 15 min before dissipating. The RISR electron density enhancement associated with this auroral arc is shown at the bottom. These data cover a time period of approximately 50 min near 10:00 UT. The electron density enhancement lasted 5 min, which

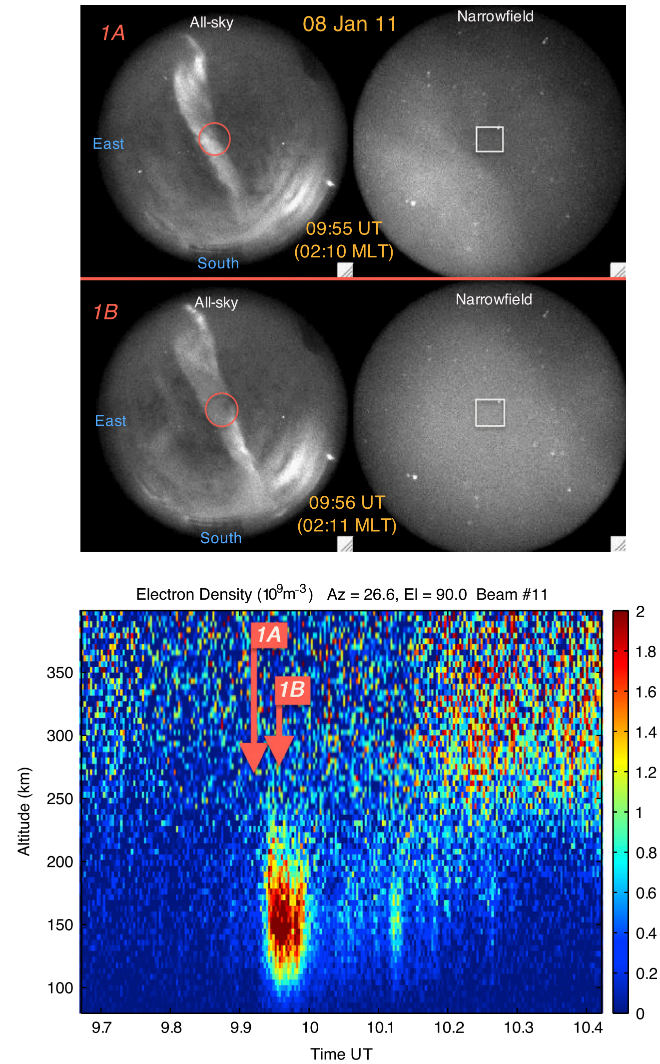

Fig. 1. All-sky (left), corresponding narrowfield image (right) and electron density (bottom) for a bright North-South aligned auroral arc passing over Resolute Bay on 8 January 2011. (A) At 09:55 UT (02:10 MLT) and (B) at 09:56 UT (02:11 MLT). North is at the top and East is to the left. The electron density profiles cover ~50 min near 10:00 UT and the color scale is $\times 10^9\ m^{-3}$.

corresponds to the time it took for the auroral arc to pass through the zenith.

The long pulse of the radar (480 μs) corresponds to approximately 72 km of range smearing. Thus, accurate determinations of the altitude of the electron density enhancements cannot be made. In this example, the approximate altitude of the peak auroral ionization is 150 km, which is higher than what is typically observed for aurora in the oval (110–140 km) with the same long pulse. Using the simple model of Rees (1963), 150 km altitude corresponds to precipitating electrons with a characteristic energy of ~1–2 keV, which is indeed lower than that typically observed in the auroral oval. The enhanced ionization extends from near 100 km to 225 km in altitude, indicating that there is a large range of electron energies present in the precipitating population.

At a later time on that same night a mostly East-West aligned arc was observed, near 16:07 UT (08:22 MLT), in the morning sector. Fig. 2 is an all-sky image of this thin auroral arc structure that formed just before sunrise which was approximately 5 km wide and lasted for approximately 5 min. The bright portion on the left is the sunrise, hence the imager saturated. While the arc