Modelling of relative mode power received on RRI experiment on ePOP satellite mission

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Abstract

The Cascade Demonstrator Small-Sat and Ionospheric Polar Explorer (CASSIOPE) satellite is scheduled to be launched in 2011. The satellite will carry a suite of eight scientific instruments comprising the enhanced Polar Outflow Probe (ePOP). One instrument is the Radio Receiver Instrument (RRI) which will be used to receive HF transmissions from ground transmitters such as the Super Dual Auroral Radar Network (SuperDARN) array. Magnetoionic polarization and propagation theory has been used to model the relative power that SuperDARN delivers to the Ordinary (O) and Extraordinary (X) modes of propagation. The geometry of the radars and magnetic field results in the X-mode dominating the transmitted signal when the modelled wave propagates northward and is nearly perpendicular to the magnetic field lines. Other propagation directions (i.e., above or southwards of the radar) results in propagation which is anti-parallel to the magnetic field lines and an equal splitting of transmitted power between the O- and X-modes occurs. For either high transmitting frequencies or low ionospheric electron densities, the range of latitudes that signal will be received at the satellite is quite large (up to $\sim 90°$ of latitude). Conversely, for lower transmitting frequencies or higher ionospheric electron densities, the latitudinal range that signal will be received over is smaller. These relative mode power calculations will be used to characterize the average electron density content in the ionosphere or to provide a measure of relative absorption in the D- and E-regions when the satellite passes through the field-of-view of a SuperDARN radar.

1 Introduction

The Canadian designed and built Cascade Demonstrator Small-Sat and Ionospheric Polar Explorer (CASSIOPE) small satellite will be launched in 2011 [1]. The satellite bus will consist of two payloads, a commercial data storage and forward system called Cascade and a scientific group of instruments called the enhanced Polar Outflow Probe (ePOP). The scientific portion consists of particle detectors, active and passive radio experiments, an auroral imager, a magnetic field detector, and a GPS system. The scientific goals of ePOP are to study outflows of particles from the polar regions, radio wave propagation, and ionospheric tomography [1]. Radio experiments will use the Radio Receiver Instrument (RRI) on ePOP [2-4]. The RRI is a radio receiver that is fed by four 3-m dipole antennas. Each antenna can operate as a separate monopole, or in pairs as two crossed (perpendicular) 6-m dipoles. The RRI will measure electric fields between 10 Hz and 18 MHz. One transmitter source for the RRI experiment is the ground-based HF Super Dual Auroral Radar Network (SuperDARN) radars [5]. In this paper, the polarization state of the SuperDARN radars is examined and more specifically the relative amount of transmitted power that will be distributed between each of the two magnetoionic modes of propagation is modelled.

2 SuperDARN Relative Mode Power Distribution

Following and building upon the formulation given in *Budden* (1961) [6], a general elliptical polarization state of a propagating magnetoionic wave is defined for the two allowed magnetoionic propagation modes for any point of the wave along its propagation path in the ionosphere. This new formulation provides an

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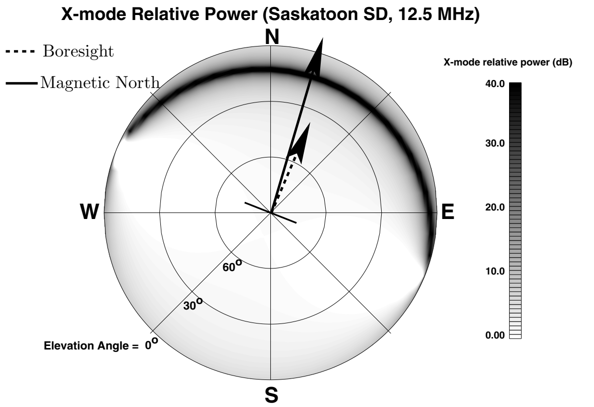

Figure 1: Relative power delivered to the X-mode (equation 1) at 12.5 MHz from the Saskatoon SuperDARN as a function of elevation and azimuth angles.

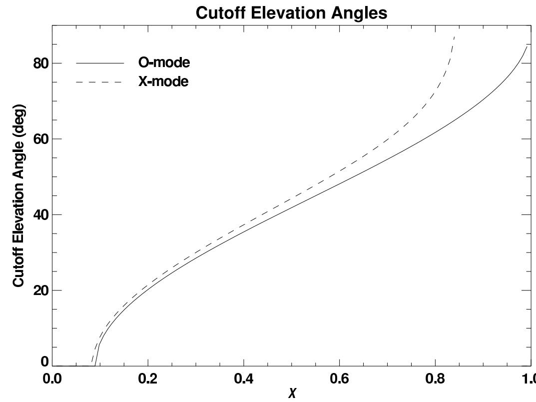

Figure 2: Cutoff elevation angles as a function of the ratio X $(= \omega_p^2/\omega^2)$ at the location of the peak electron density for the O-mode (lower curve) and X-mode (upper curve). Waves launched from the Saskatoon SuperDARN at lower elevation angles than these will be refracted back to Earth and not detected by the RRI on ePOP.

expression for the amount of power that is injected into the X-mode relative to the O-mode, given an initial polarization state. The relation for the relative power that is delivered to the X-mode compared to the O-mode (R_e), which is the quantity presented in the following sections, in units of dB is:

$$R_e = 10 \log_{10} \left[\frac{e_x^2 + e_y^2}{o_x^2 + o_y^2} \right], \tag{1}$$

where o_x and o_y represent the principal of the O-mode polarisation ellipse and similarly, e_x and e_y represent the same for the X-mode polarisation ellipse.

Equation 1 and supporting equations were used to determine the relative power that a SuperDARN radar distributes to either mode of propagation. An example is presented in Fig. 1. The edge of the large circle represents 0° elevation angle, while the centre of the circle represents 90° elevation angle or directly vertical. An X-mode relative power of 0.0 dB (white on the contour plot) would correspond to equal splitting between the two propagation modes. The elevation and azimuth angles which show darker shades on the plot indicate higher relative X-mode power is transmitted in these directions. From this figure, it is immediately apparent that there is a band of elevation angles north of the transmitter where the transmission is dominated by the X-mode. Meanwhile, above and south of the radar, the two transmission modes are roughly equal in power. The same analysis was performed similarly located SuperDARN radars in Canada and, in general, the results are quite similar. The X-mode relative power maximum is roughly centred on geomagnetic north and decreases in elevation for an increase in geomagnetic latitude.

3 Cutoff Elevation Angles and Power Distributions Detected by RRI

The preceeding section dealt with the power distributions of the O- and X-modes from a SuperDARN perspective. For the ePOP/RRI experiment, the behaviour of the transmitted waves from SuperDARN as they propagate through the ionosphere to the orbiting RRI receiver was examined. The main finding of the modelling of the relative power, for either mode received by the RRI, was that waves launched at lower elevation angles will not escape the ionosphere. These waves will be internally reflected by the highly dense F-region peak and thus will not be detected by the orbiting RRI receiver. The peak ionospheric electron density at SuperDARN latitudes can range from below 10^{11} m^{-3} to above 10^{12} m^{-3}. With this range of possible densities, the cutoff elevation angle (the minimum elevation angle for which a wave of a given

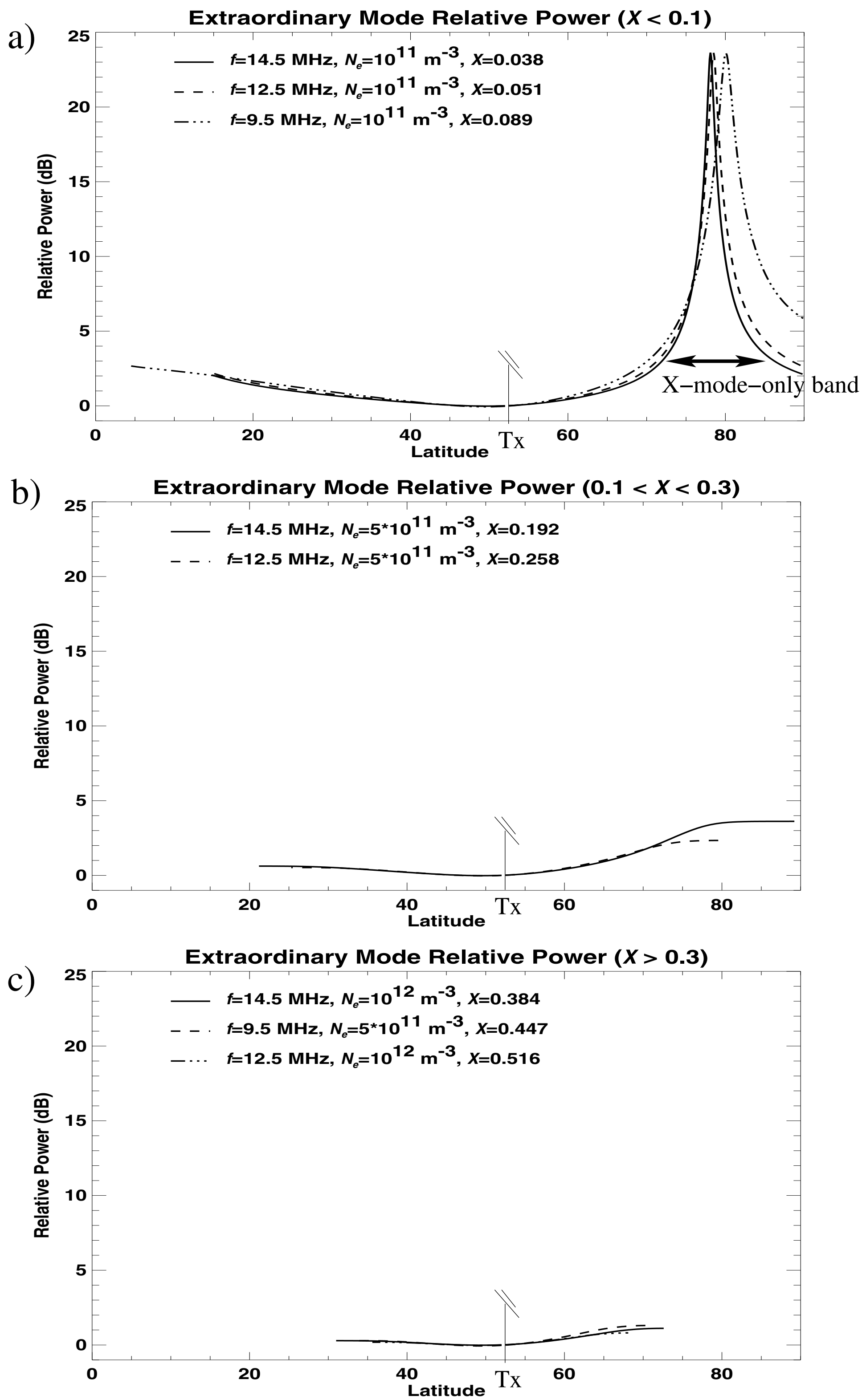

Figure 3: Modelled X-mode relative power that will be received by the RRI on ePOP. Panels a), b), and c) illustrate transmitter frequency and ionospheric peak density combinations which correspond to; $X < 0.1$, $0.1 < X < 0.3$, and $0.3 < X$, respectively. The modelling assumes a north-south satellite orbit at 1500 km directly over the Saskatoon SuperDARN radar (latitude – 52.16°N).

frequency can propagate through the F-peak and reach the satellite) can vary substantially. Fig. 2 is a plot of the cutoff elevation angles for the Saskatoon SuperDARN radar. The relative mode power that is to be received by the RRI on ePOP as it orbits over the Saskatoon SuperDARN radar was modelled for a variety of electron density and radar frequency combinations and is presented in Fig. 3.

4 Conclusions

The polarization along the paths followed by SuperDARN radar rays has been studied in preparation for the upcoming ePOP satellite mission (RRI experiment) to be launch in 2011. The relative power of the two modes of propagation as a function of propagation direction and frequency has been calculated and presented. It has been determined that the horizontal linearly polarized wave that is transmitted by the radars resembles the X-mode for propagation north of a transmitter, resulting in a band of azimuths where the X-mode dominates the transmitted signal. Meanwhile, above and south of the radars, the transmitted signal is split roughly equally between the O- and X-modes, because the modes are circularly polarized states of roughly equal power resulting from the initial linear wave. The relative mode power that will be received as a function of satellite latitude was determined for typical electron density profiles. More detailed analysis and conclusions can be found in *Gillies et al.* (2010) [7].

5 Acknowledgments

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