The POLARDARN Concept

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Abstract

One exciting new future direction for SuperDARN involves placing a pair of SuperDARN radars to cover the polar cap in the northern hemisphere. This possibility is discussed with regard to disturbed electric field observations in both the polar cap and auroral zones and optical red line (630 nm) observations in the polar cap during northward IMF conditions. Although the conductivity may be very low in the polar cap, with the result that ground-based magnetometers give small responses, the HF radar observations indicate that the electric field is not weak and that the convection can be quite dynamic. Ray-tracings for the proposed sites at Rankin Inlet and Inuvik in Canada are presented to illustrate the viability of the propagation conditions, and the excellent coverage of the region around the north magnetic AACGM pole. The possibility of using the same sites for HF radar observations looking equatorward to the lower latitude portion of the auroral zone where substorms are initiated also is discussed.

INTRODUCTION

The SuperDARN network has now grown to such an extent in the northern hemisphere that the longitudinal coverage extends all the way from Alaska eastward to Finland in the auroral zone and equatorward portion of the polar cap. There is, however, a Agap in the cap@ that would be relatively easy to fill with a single pair of SuperDARN radars. The north magnetic pole is located, in AACGM coordinates, near Eureka (88.68E MLAT) in the Canadian Arctic islands. This displacement of the magnetic pole toward Canada from the north geographic pole is quite advantageous for the reason that there are well-populated Canadian sites that are ideal for SuperDARN purposes. For example, Inuvik and Rankin Inlet have separation of ~1900 km from each other and are both virtually identical distances, also about 1900 km from Eureka (all distances are great circle distances).

The polar cap has been somewhat of an ignored region because it has been physically difficult to install equipment in these regions. However, the SuperDARN results from high latitudes show that the convective flows and associated electric fields are often reasonably strong even though the conductivities and the resulting magnetic perturbations shown by magnetometers may be low. Furthermore, the polar cap region can be surprisingly active even during prolonged northward IMF conditions (papers 308 and 1110, this meeting).

Recently, there have been a number of MHD models (Bargatze et al., JGR, 104, 14583, 1999; Song et al., JGR, 104, 28361, 1999: Usadi et al., JGR, 98, 7503, 1993) which show that the polar cap during positive IMF Bz conditions is a key region for monitoring the rate of closure of the field lines, and that the magnetosphere is almost completely closed after 4 or 5 hours of northward IMF (see Figures 1, 2, and 3). On the other hand, there is an abundance of SuperDARN data showing reverse convection cells (e.g. paper 308 of this meeting; also Huang, Chao-Song, D. Andre, G. J. Sofko, and A. V. Kustov, J. Geophys. Res., 105, 7419 - 7428, 2000) and supporting optical data (McEwen and Zhang, GRL, 27, 477, 2000) that seem to contradict these predictions. In the optical data, a meridian scanning photometer (MSP) was installed at Eureka, very near the north magnetic pole. The MSP was placed on a rotatable table such that the scans of the oxygen red line at 630.0 nm always were taken in the dawn-dusk direction (Figure 4). During a protracted period of northward IMF, the MSP scans on January 19, 1998, shown in Figure 5, showed a very clear transition from strong intensities in the 80 - 85 MLAT intervals to very weak intensities in the central polar cap. This leads the authors to conclude that the sharp boundary between the central cap weak intensities and the equatorward strong intensities marks the transition between open and closed field lines, in contradiction to the supposedly completely closed state predicted by the MHD models. There is another interesting By-associated effect shown clearly in the photometer data, previously mentioned by Valladeres, C. E., H. C. Carslon Jr., and K. Fukui (JGR, 99, 6247, 1994), namely the formation of arcs which move across the polar cap from the dawnside to the duskside when By is positive, or from the duskside to the dawnside when By is negative. This motion is readily explained in terms of the convection in the back (antisunward) portion of the single Areverse convection cell@ formed in the polar cap when $1 < |Bz/By| < 2$, as it is for these Jan. 19/98 arcs. As will be reported in paper # 308 on the evolution of multi-cell convection during northward IMF conditions by Huang et al., there are two reverse convection cells in the polar cap when Bz is quite dominant, i.e. $|Bz/By| > 2$, but only one when $1 < |Bz/By| < 2$. These cells lie almost entirely on the dayside, with the Aback@ (antisunward) portion of the cell involving flow across the polar cap along the dawn-dusk line where the MSP scans reported by McEwen and Zhang occur. In agreement with the optical arc movement, the convective flows are indeed from dawn to dusk for the single reverse cell formed when By is positive, and from dusk to dawn when By is negative. In other words, both the convection and arc motion on the antisunward side of the reverse convection cell have the direction of the IMF By component. The SuperDARN results clearly show that the Aback@ (antisunward) side of the reverse convection cell lies almost along the Y axis of the GSE coordinate system, i.e. along the dawn-dusk meridian (where the MSP scans at Eureka occur), and not on the nightside of the polar cap as shown in the MHD model of Song et al. (1999).

It is clear that the SuperDARN polar cap region measurements could provide data important for the understanding of high-latitude physical processes, for studies of the open-closed field line topology under a wide range of IMF conditions, for the study of reconnection-associated convection during Bz+ IMF, for the detailed study of multi-cell convection and the evolution of reverse convection cells during IMF Bz+ conditions, and for the high-latitude completion of the global convection patterns and the resulting evaluation of the cross-polar-cap potential under all IMF conditions.

THE GEOMETRY OF PolarDARN

As shown in the Figure for PolarDARN North, a single pair of radars at Rankin Inlet (62.82 N; 93.11 W geographic; 73.17 N, 28.20 W AACGM) and Inuvik (63.00 N, 133.00 W geographic; 71.15 N, 86.5 W AACGM) would completely cover the polar cap region, with the boresites being 20EE of N for Rankin, 15EE of N for Inuvik.

The key sites in the Canadian Arctic at which there is ground-based scientific instrumentation useful for the support of the PolarDARN radars are Eureka and Resolute Bay. Eureka (80.00 N, 85.93 W geographic; 88.68 N, 44.62 W AACGM) lies very near the AACGM north geomagnetic pole on Ellesmere Island, where the ASTRO Lab of the Meteorological Service of Canada (MSC) contains a number of optical, magnetic and radio experiments operated by Canadian and international space scientists. The great circle distances (GCDs) to Eureka are 1926 km and 1869 km from Rankin and Inuvik, almost equal to the 1897 km GCD between the radar sites Rankin and Inuvik. Thus Eureka is on beam 4 at range cell 40 from Rankin (range 1994 km for an assumed 325 km scattering height), and on beam 9 at range cell 39 from Inuvik (1937 km range), for the normal Common Mode scan (45 km resolution with initial range 180 km).

Resolute Bay (74.68 N, 94.90 W geographic; 83.56 N, 43.50 W AAGCM) is the site of several Canadian experiments and the US Polar Cap Observatory building (which could be used for campaign measurements of one the proposed portable ISR systems). It lies along beam 15 at range cell 31 (1937 km for the 325 km scattering height) for the proposed Inuvik radar, and along beam 2 at range cell 27 (1994 km range) for the Rankin Inlet radar.

Finally, it should be noted that, because there is frequently rather only small absorption in the polar cap region, the PolarDARN beams might possibly reach Svalbard by means of multiple-hop propagation. This could lead to collaborative experiments with the SPEAR (Space Plasma Exploration by Active Radar) system, because Svalbard lies relatively near the boresites of the proposed PolarDARN radars. If the nominal SPEAR location is taken to be at Longyearbyen ((78.15 N, 16.04 E geographic), then relative to Inuvik, the radar range is 3697 km (range cell 78) along beam 5; relative to Rankin Inlet, the range is 3716 km (range cell 79), along beam 9. Since SPEAR in its high-power Aheater@ mode can artificially create VLF and ULF electromagnetic waves, short-scale electrostatic plasma density waves, and irregularities in the ionosphere, there would be favourable conditions for backscatter provided there is an open propagation path.

PROPAGATION IN THE POLAR CAP

It is critical that there be propagation paths available to reach scattering regions in the polar cap, and to establish this, ray tracing was performed using standard electron density (N_e) profiles for locations roughly 500 km north of the radar sites. As shown in the figure labelled inuvik_1999122100.prg, the electron density extremes are the winter maximum W 00 UT (the curves are labelled in UT, which is about 9 hours ahead of local solar time), and winter minimum W 12 UT profiles. During the summer, N_e is fairly constant because the polar cap is illuminated all day long, so only the summer profile S 00 UT was used.

The propagation raypaths are shown on the next 3 figures, for 1Esteps in elevation from 5E to 50E(the curves at 10, 20 , 30 and 40 are slighter darker). The 10.2 MHz propagation paths from Inuvik are shown on plots of the ray altitude above ground (GALT) versus great circle distance (GCD) from the radar, for an assumed heading of 30E E of N (boresite is 15E). For the winter maximum (labelled Dec 21 00 UT), Eureka (at GCD ~ 1900 km) and Resolute (at GCD 1510 km) are easily accessible by the F-region one-and-a-half hop mode. The summer plot (June 21 00 UT) shows that there is a well-established E-region in addition to the F-region. At this time, Eureka is accessible by one-and-a-half hop modes to both the E-and F-regions, but the propagation to the E-region would have to be at a much smaller elevation angle than to the F-region (interferometer measurements would be useful here). The curves show that Resolute (1510 km GCD) may not be accessible by F-region modes, but is certainly accessible by the one-and-a-half hop E-region mode. The DEC 21 12 UT winter minimum N_e profile is the least suitable for propagation, but it shows that Resolute Bay is certainly available through direct F-region propagation at the low elevation angles, while Eureka may be accessible by that mode too if there are perturbations in the N_e profile that would allow somewhat greater GCDs for the rays than are shown on the figure. In building the PolarDARN radar, the antenna costs may be greatly reduced if only a single frequency is used, and 10.2 MHz seemed to be a good compromise frequency for the range of N_e values expected during the year.

ANTENNA

The above ray-tracing diagrams at 10.2 MHz were consistent with the use of a single frequency radar. Actually, as shown in Figure 11-11 of the textbook **Antennas** (John D. Kraus, McGraw Hill, 1950), if the antenna consists of two half-wave dipoles separated by a quarter wavelength, and if these are fed with a phase difference δ = 90E, the radiation pattern is a fairly uniform in the forward direction and negligible in the back direction (middle pattern of second row). In fact, it appears that the frequency could be shifted somewhat (this has the effect of changing the separation d) without serious degradation of the pattern. The use of such a simple antenna could lead to substantial savings, compared to the log-periodic structures currently in use.

PolarDARN SOUTH

There is some merit in looking equatorward, rather than poleward, from the PolarDARN sites. For example, substorm onset appears to occur at relatively low magnetic latitudes of about 65E or so. This is too low a latitude for a normal SuperDARN radar; the auroral scatter is mixed in with meteor scatter. From Rankin Inlet and Inuvik, however, one is far enough north that it is possible for a pair of radars to have overlapping fields-of-view at the lower magnetic latitudes of the plasmatrough, plasmapause, and the substorm onset region, A figure is shown for PolarDARN South, with boresite directions of 150E for Inuvik, 240E for Rankin Inlet. It does appear that a separate antenna system would be needed for PolarDARN South. While this would be easy to implement, it would certainly add to the costs. If a single frequency band could be used for both PolarDARN North and South, then the total cost for the two arrays might still be substantially less than for the present SuperDARN log periodic antennas, but that has yet to be evaluated.

SUMMARY

Now that the SuperDARN network in the northern hemisphere is so extensive in the auroral zone and equatorward portion of the polar cap, the last remaining link between Canada and Scandinavia to provide full latitudinal coverage over the polar cap could be readily achieved with a single pair of radars, and the sites Inuvik and Rankin Inlet in Canada appear to be ideally located. A good deal of interesting physics could be examined with a more thorough study of the polar cap region. The costs of the system could be reduced by the use of a simple antenna system, and by operating within a small frequency band.

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