Those DARN Radars: New Directions for the Super Dual Auroral Radar Network

***Baker, J. B. H.*[1], J. M. Ruohoniemi[1], S. G. Shepherd[2], K. A. McWilliams[3], R. A. Greenwald[1], W. A. Bristow[4]**

[1]The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723-6099, USA, joseph.baker@jhuapl.edu

[2]Thayer School of Engineering, Dartmouth College, 8000 Cummings Hall, Hanover, NH 03755-8000, USA

[3] Department of Physics and Engineering Physics, University of Saskatchewan, 116 Science Place, Saskatoon, SK S7N5E2, Canada

[4]Geophysical Institute, University of Alaska, 903 Koyukuk Drive, Fairbanks, AK 99775, USA

Abstract - The Super Dual Auroral Radar Network (SuperDARN) measures coherent backscatter from plasma irregularities drifting under the influence of ionospheric electric fields. These measurements, obtained continuously, provide valuable information about the electrodynamics of the coupled magnetosphere-ionosphere system over extended spatial scales and with high time resolution. At the present time there are 21 radars operating in both hemispheres and there are plans for the construction of many more. In this paper we describe some of the recent developments within SuperDARN with a particular emphasis on describing a new antenna design and the recent expansion of the network to higher (PolarDARN) and lower (StormDARN) latitudes.

1. Introduction

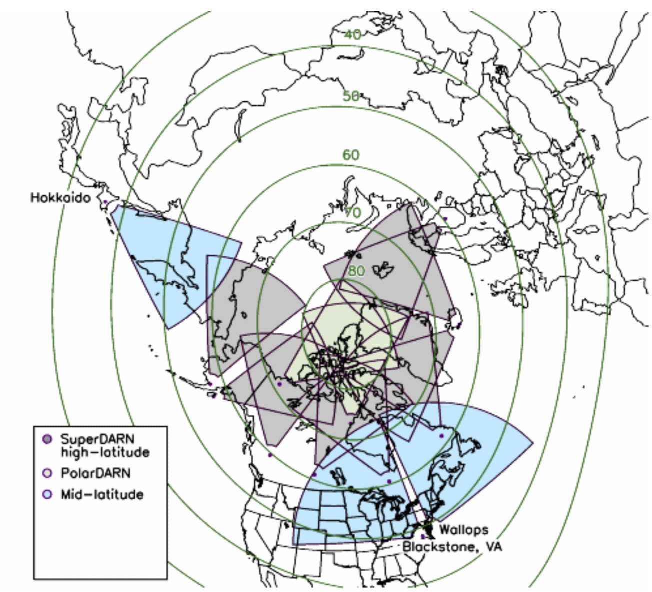

Figure 1: Fields-of-view of the northern hemisphere SuperDARN radars currently operational: original array in grey; PolarDARN radars in green; mid-latitude radars in blue

SuperDARN is a network of High Frequency radars for ionospheric research that has been developed through the collaboration of more than a dozen countries. The primary objective of SuperDARN is to provide direct, continuous, global-scale observations of high-latitude ionospheric convection. SuperDARN radars are sensitive to scatter from decameter-scale irregularities in the ionospheric plasma density. These irregularities tend to be aligned along the magnetic field direction and present an appreciable cross-section for backscattering only when the HF ray is within a few degrees of perpendicular to the magnetic field. This orthogonality condition is achieved via refraction in the ionosphere. At F-region heights, the Doppler shift of the backscattered signal is directly related to the plasma convection velocity and the ionospheric electric field [1, 2]. The ability of SuperDARN radars to measure plasma drift velocities at a particular time and location is dependent on the presence of plasma irregularities to provide backscatter targets for the radar signal.

The design of the SuperDARN radars has evolved significantly since the original Goose Bay radar became operational in 1983 [3]. A recent review article describes the characteristics of the radars in some detail [4]. In brief, the standard SuperDARN radar utilizes an array of electronically phased antennas that can be steered in 16 distinct beam directions within a field-of-view spanning an azimuth sector of approximately 52°. A special multi-pulse sounding sequence is used to unambiguously determine the range and Doppler velocity of the ionospheric irregularities out to ranges in excess of 3000 km. A secondary antenna array provides vertical angle-of-arrival information to determine the altitude of the irregularities. All SuperDARN radars operate continuously using a variety of sounding modes. In standard operation the temporal resolution is 1-2 minutes and the range resolution is 15-45 km. While there are some hardware differences between the radars, each is controlled with a common set of software and produces identical data products. This approach enables straightforward analysis of data obtained from the entire SuperDARN network.

One standard data product that employs measurements from multiple radars is the generation of hemispheric patterns of ionospheric convection [5]. The technique solves Poisson's equation to obtain a solution for the electrostatic potential as a weighted least squares fit to a spherical harmonic expansion of associated Legendre functions. In regions of poor data coverage velocity estimates from an IMF statistical model are used to constrain the solution from becoming unphysical. In recent years, SuperDARN convection patterns derived from this procedure have become an invaluable tool for space weather now-casting and investigating a number of topics in magnetosphere-ionosphere-thermosphere coupling [e.g. 6].

2. The Wallops Radar Antenna Design

In the past, the ability of SuperDARN to measure ionospheric convection was typically limited during extreme geomagnetic disturbances because the auroral disturbance expanded equatorward of the radar sites and the radars suffered from absorption of signal in an ionosphere thickened by auroral precipitation. To overcome these shortcomings it was decided to construct a SuperDARN radar at middle latitudes on the grounds of the NASA Wallops Flight Facility. This radar began operations in May 2005. Early results have demonstrated that during increased geomagnetic activity the Wallops radar is able to measure the expansion of auroral electric fields to middle latitudes and, as a result, the average SuperDARN cross-polar cap potential is increased by 25% [7]. Since the Wallops radar became operational, two additional SuperDARN radars have been constructed at Hokkaido, Japan, and Blackstone, Virginia (see Figure 1).

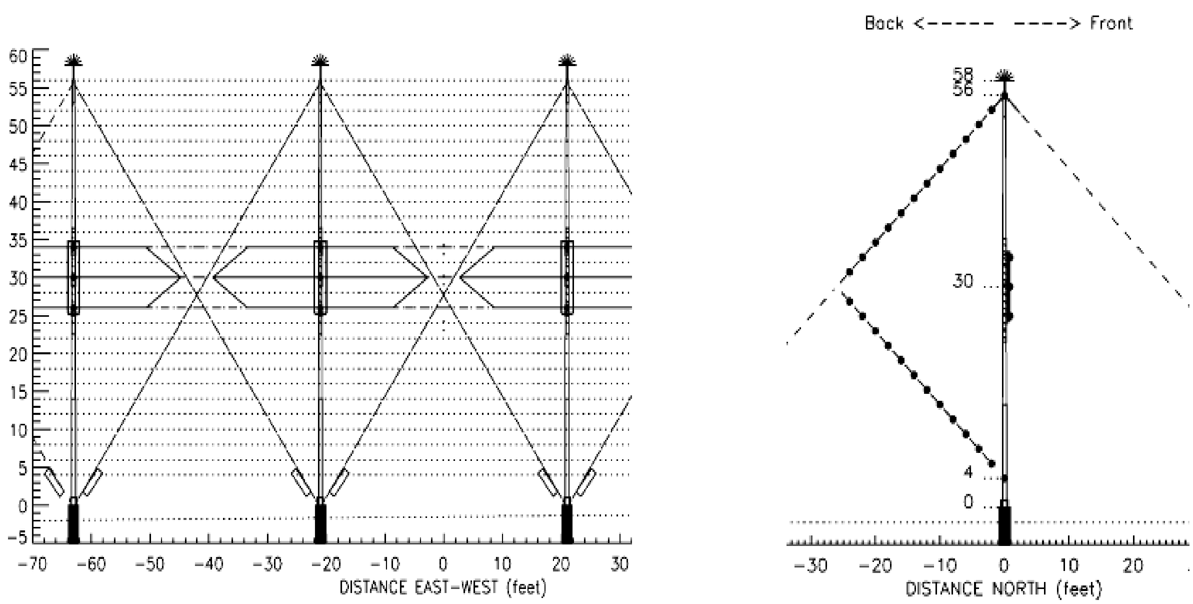

Figure 2: Front view (left) and side view (right) of the SuperDARN twin-terminated folded-dipole antenna design. Each antenna consists of two trapezoid loops of 12-gauge wire strung between 55-foot traffic poles using 3 horizontal lengths of Kevlar cable (dashed lines). The antenna feed point is a 25:1 balun at the center of a plate mounted to the pole at 30 feet and the termination is in 100-ohm resistors at both ends of the plate. The overall shape of the antenna is a split hexagon when viewed from the front. Behind the antennas is a corner reflector running the length of the entire array (dotted lines in the left panel; heavy dots in the right panel) which directs power forward.

Apart from being the first SuperDARN radar built at middle latitudes, the Wallops radar was also the first to use a new antenna design. Earlier generation SuperDARN radars used log-periodic antennas constructed by the Sabre Communications Corporation that were relatively expensive. To reduce the cost of the antennas a considerable modeling effort was directed toward identifying a simple and inexpensive alternative to the Sabre antenna. The result shown in Figure 2 is an innovative design that greatly reduces the material, installation, and maintenance costs of the radar, while leading to improved flexibility and reliability. Each antenna is a twin-terminated folded-dipole constructed from standard 12-gauge antenna wire. The antenna possesses nearly an octave of bandwidth thus making it ideal for broadband phased-array radar applications. The poles used to support the antenna wires are standard highway lighting poles that have been modified to allow attachment of mounting hardware for the antenna guys and a lightning disperser. Poles are mounted onto concrete piers using conventional street lighting construction techniques. Kevlar guy lines provide stability to the poles as well as supporting the wires for the antennas and a rear reflector screen to direct power forward.

3. PolarDARN

PolarDARN is a pair of HF radars with overlapped fields of view located at Rankin Inlet (73.2° AACGM LAT) and Inuvik (71.2° AACGM LAT) (see Figure 1). The primary PolarDARN science goal is to study the dynamics of convection, radio scattering conditions, and field-aligned currents in the polar cap region and at the poleward edge of the auroral oval. These radars are also ideally located to act as the coherent radar complement to the AMISR Resolute Bay (MLAT 83.9° N) ISR radars. The PolarDARN radars have been fully operational since May 2006 (Rankin Inlet) and November 2007 (Inuvik).

When compared with other SuperDARN radars the PolarDARN radars have operated very successfully during the quiet solar wind conditions at the end of Solar Cycle 23. In spite of the often extremely quiet conditions, the Rankin Inlet and Inuvik radars are providing virtually continuous echoes 24 hours a day. The bulk of these echoes are from anti-sunward streams at the equatorward edge of the polar cap and/or poleward edge of the auroral oval, rather than from the interior of the polar cap proper. On the night-side these echoes are characterized by narrow spectral width. This offers a vivid contrast with the large spectral widths of the day-side echoes in the cusp region that have been observed by the other SuperDARN radars for many years. Convection patterns calculated using PolarDARN data reveal a very dynamic polar cap, with substantial changes in the convection pattern from one minute to the next. Finally, during more disturbed conditions, the PolarDARN radars are sometimes able to detect echoes simultaneously at both extremities of the polar cap: at the poleward edge of the auroral oval in the Canadian midnight sector and the dayside cusp region in the European sector.

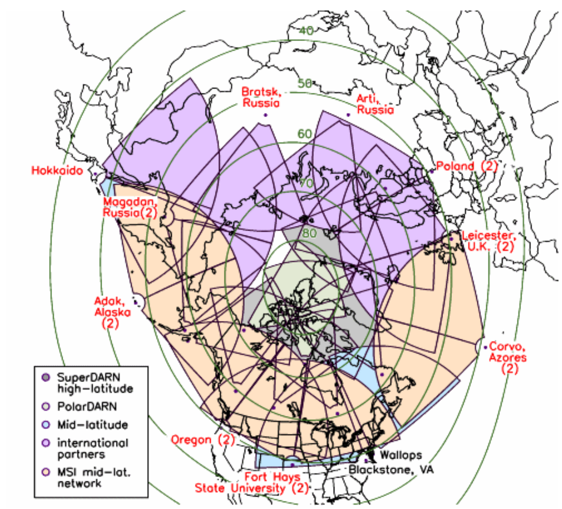

Figure 3: A vision for future expansion of SuperDARN with eight additional mid-latitude radars in the western hemisphere (orange) and a mix of six high and middle latitude radars in Eurasia (purple).

4. Future SuperDARN Expansion

At the present time there are plans to deploy many additional SuperDARN radars in both the northern and southern hemispheres. In the southern hemisphere there are plans to deploy new radars at the Chinese base at Zhongshan, at DOME-C, and at the South Pole station. In the northern hemisphere there is a push to establish a comprehensive mid-latitude network of radars that will overlap with the existing array at higher latitudes and expand the coverage equatorward to 50˚ geomagnetic latitude. Figure 3 shows how this could be achieved with the construction of several new radars: eight in the western hemisphere (shown in orange) and 6 in Eurasia (shown in purple). In the

Eurasian sector there is a mix of radars at both high and middle latitudes to (1) close the gap in local time coverage at high latitudes and (2) expand the coverage equatorward. These additional radars will provide continuous global-scale coverage of ionospheric electric fields and plasma convection from the plasmasphere to the central polar cap, and specification of the instantaneous convection pattern over a greater range of geomagnetic conditions than can be accomplished with the existing SuperDARN network.

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