The Blackstone SuperDARN HF Radar

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Synopsis

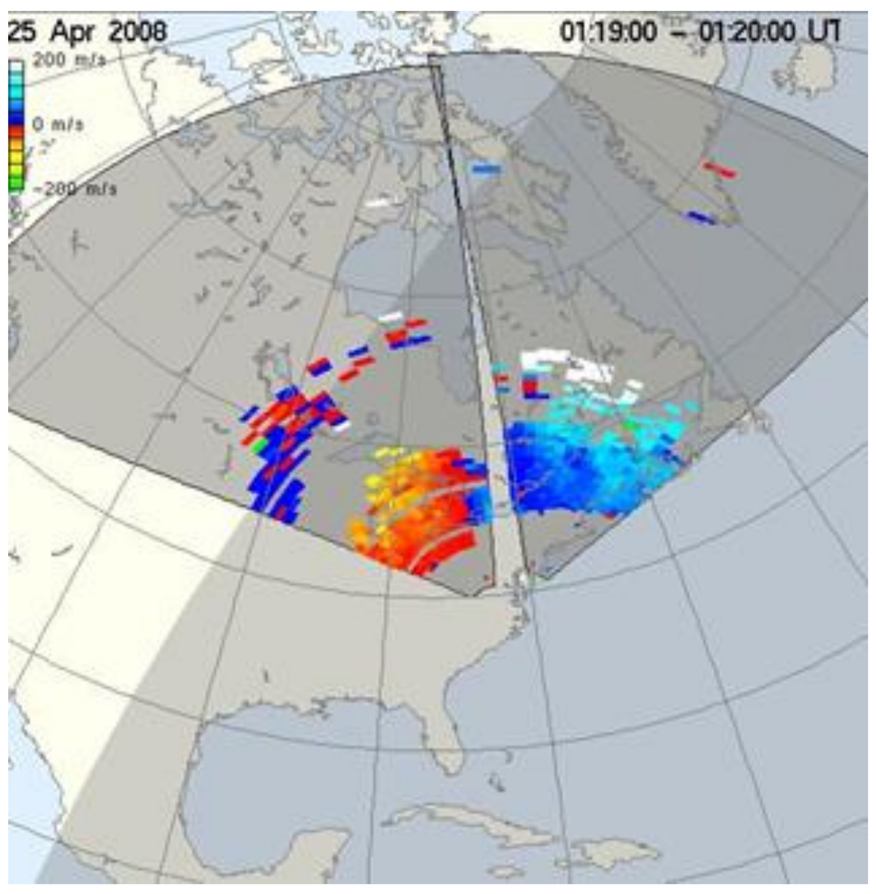
The Blackstone radar is located on the grounds of the Virginia Tech Southern Piedmont Agricultural Research and Extension Center (AREC). The radar is funded, along with the other radars of the U.S. collaboration, by the National Science Foundation (NSF). The Principal Investigator (PI) is Prof. Mike Ruohoniemi of the Virginia Tech (VT) Department of Electrical and Computer Engineering (ECE) and the senior members of the VT group are Prof. Jo Baker, Dr. Bharat Kunduri, and Mr. Kevin Sterne (RF engineer). The radar operates within the HF frequency band and observes primarily backscatter (echoes) from the ionosphere (a weakly ionized layer of the atmosphere that begins at about 90 km altitude), from Earth's surface after reflection from the ionosphere ('groundscatter'), and from trails left by meteors. The data are applied to understand and mitigate the variable conditions in Earth's near-space environment, which are collectively known as 'Space Weather' and also to understand HF ray propagation in the ionosphere on the Over-The-Horizon (OTH) radar principle. The radar contributes to the data stream of the international Super Dual Auroral Radar Network (SuperDARN) collaboration, which counts more than 30 operating radars and 16 PI institutions in eleven countries.

Introduction

SuperDARN radars have a wide field-of-view that covers large areas of the ionosphere. Below are common features that appear in the data of the radars. By verifying that the non-grainy near range features are Es, the radars could be utilized as an additional tool in detecting Es layers in the ionosphere.

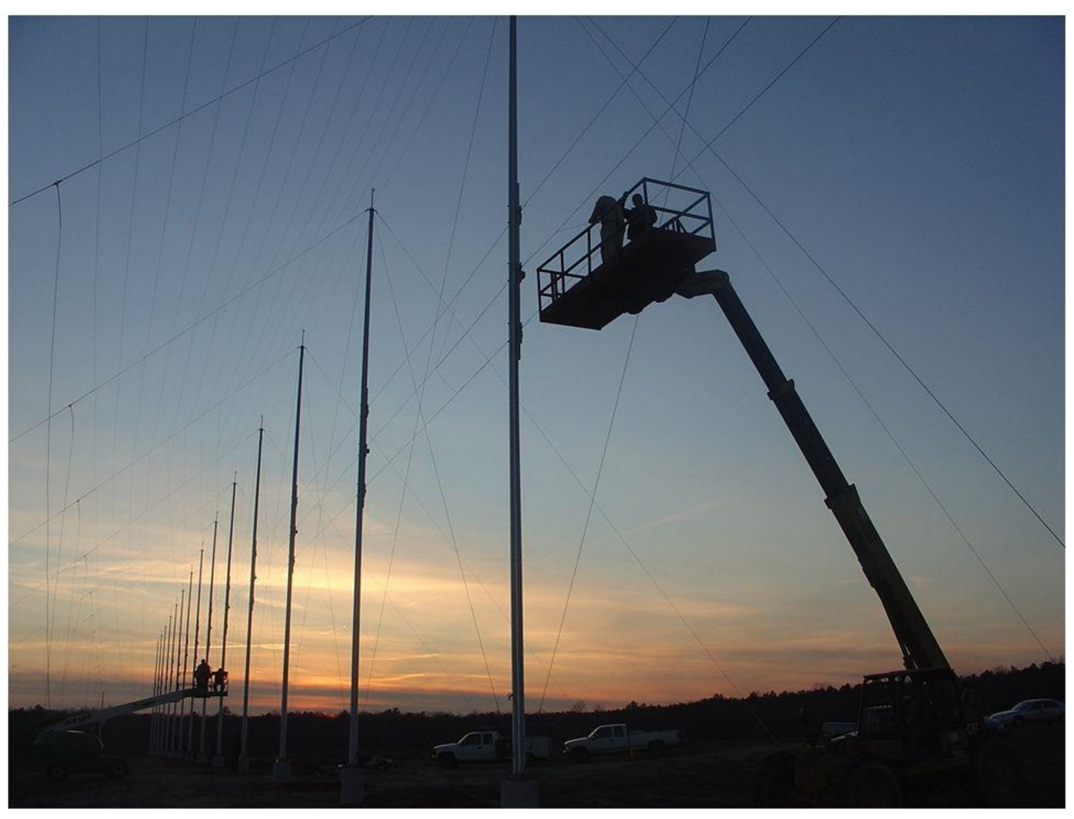
Background

The first radars of the SuperDARN type were built at high latitudes such as northern Canada and Scandinavia in order to observe disturbances in the ionosphere associated with almost daily aurora. During large geomagnetic storms the zone of disturbance expands equatorward, making it possible to observe aurora from Virginia and places even farther south. The Blackstone radar was the third built at mid-latitudes in order to expand the coverage needed for such events. The first mid-latitude radar was built at NASA Wallops Flight Facility in eastern Virginia and the second at a site in Hokkaido, Japan by Japanese colleagues. With the success of these instruments, extensive mid-latitude chains of radars have been built across the mainland U.S. and northern China. Virginia Tech operates an additional pair of mid-latitude radars at Hays, Kansas and two older radars at sites in northern Canada (Goose Bay, Labrador and Kapuskasing, Ontario).



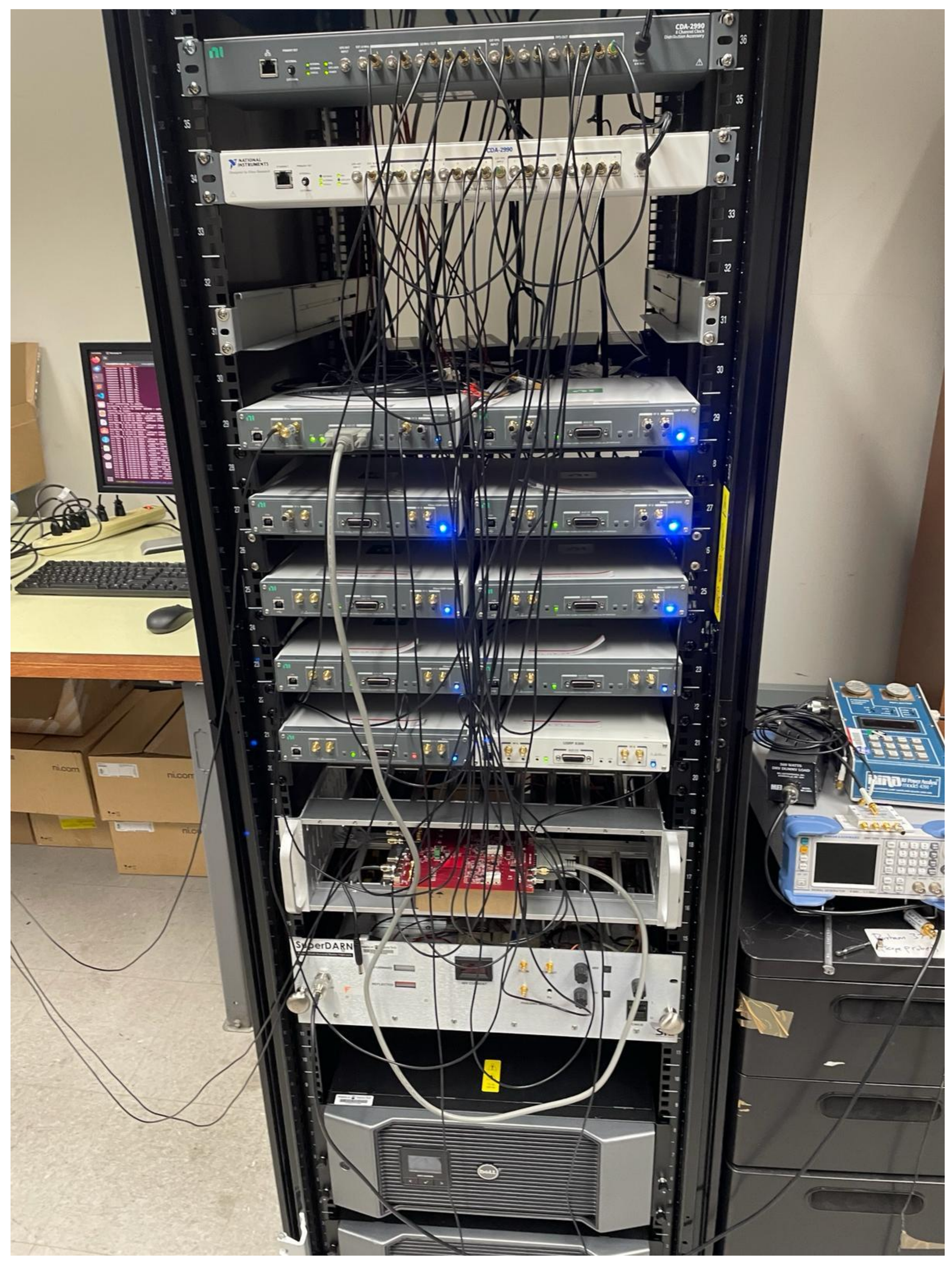
Construction

The first high-latitude radar was built at Goose Bay in 1983 by a team led by Ray Greenwald from Johns Hopkins University Applied Physical Laboratory (JHU/APL). The construction of radars to make up SuperDARN began in the 1990s. The first mid-latitude radar was built at Wallops to look towards the northeast in 2003 as a joint project of JHU/APL and NASA Goddard Space Flight Center (NASA/GSFC). A search for a second site to look towards the northwest eventually led to Virginia Tech. In 2007 initial discussions between JHU/APL and VT led to the selection of a site at the Southern Piedmont AREC, which was just being cleared from heavy forests to be prepared for pastureland. The radar proceeded to be built as a joint project of VT and the University of Leicester (UK, PI: Prof. Mark Lester), which provided an entire set of control electronics on a loan basis. First light occurred in the fall of 2008. The University of Leicester electronics operated for three years and were eventually taken back and replaced by electronics sourced by the Virginia Tech group, which had by now relocated from JHU/APL to Virginia Tech with the PI ship of the Blackstone site transferred from Ray Greenwald to Mike Ruohoniemi. Most recently the electronics have been upgraded to an entirely digital system based on USRPs. The first observations with the new electronics were made through the period of the total solar eclipse in April 2024 and produced spectacular observations.



Technical

The most visible parts of the radar are the two arrays of wire antennas mounted on 56' poles. The front array consists of 16 antennas that operate in both transmit and receive mode while the four antennas of the back array are receive-only. Both arrays are equipped with a 'screen' of wires on the backside that make up a reflector array. As a phased-array system, the antenna beam is formed and steered by electronically shifting the phases of transmitted and received signals. Cables connect from antennas through trenches to the equipment shelter. Inside the shelter, the cables connect to transmit/receive units that are mounted in two racks. Tracing back, the signals are routed from and to a rack of control electronics which is now based on a bank of USRPs, with one USRP servicing two antennas. Control is exercised by a multipurpose computer which has connections to the internet to enable data transmission and communications. The radar is operated 24/7 according to a schedule agreed upon by the SuperDARN PIs. Daily downloads with data summaries are presented on the Virginia Tech SuperDARN website.



Scientific

The radar transmits a series of pulses at a frequency between 8 and 18 MHz, searching for a quiet channel between each transmission to ensure noninterference with other users of HF spectrum. The radar typically receives returns in 50 km range bins over a total range that can extend from 200 km to over 2500 km. The returns are processed for backscatter power, Doppler velocity, and other parameters. By sweeping the beam through 16-24 azimuthal pointing directions, a fan-shaped area is covered. The scan is repeated every minute to rapidly update on changing space weather conditions.

Plots can be generated from the data showing the occurrence of backscatter with strength measured in signal-to-noise ratio. The Doppler shift of the signal is due to motion of the target. In the case of targets embedded in the ionosphere, this indicates motion of the ionospheric plasma or the 'plasma wind'. By combining maps from individual radars, a global-scale view of the circulation of ionospheric plasma is obtained, corresponding to maps of the plasma winds with pressure measured in terms of kilovolts. The velocities of the plasma vary from tens to hundreds to kilometers per second, and are much stronger during storm periods. Study of the circulation of plasma in the ionosphere - also called convection – with the SuperDARN radars reveals much about the coupling of the turbulent solar wind to the coupled magnetosphere-ionosphere system.

The backscatter generated by Earth's surface indicates vertical motion in the ionospheric layers that is due to the passage of waves in the atmosphere. Traveling Ionospheric Disturbances (TIDs) produce a characteristic pattern of enhancements and depletions in backscattered power associated with groundscatter; these correspond to wave crests and troughs in the ionospheric layer that cause focusing and defocusing of signal transmissions. The wavelengths of TIDs are measured in hundreds of kilometers and the waves have speeds of hundreds of meters per second. They are studied to understand the coupling of energy and momentum between the ionosphere and atmosphere.

Credits

The VT SuperDARN group acknowledges the support of NSF under award AGS-1935110, the support of Virginia Tech, and the support of VT Southern Piedmont AREC personnel: Dr. Carol Wilkinson (past director), Dr. Arash Rashed (current director) and Mr. Ned Jones (Farm Manager).