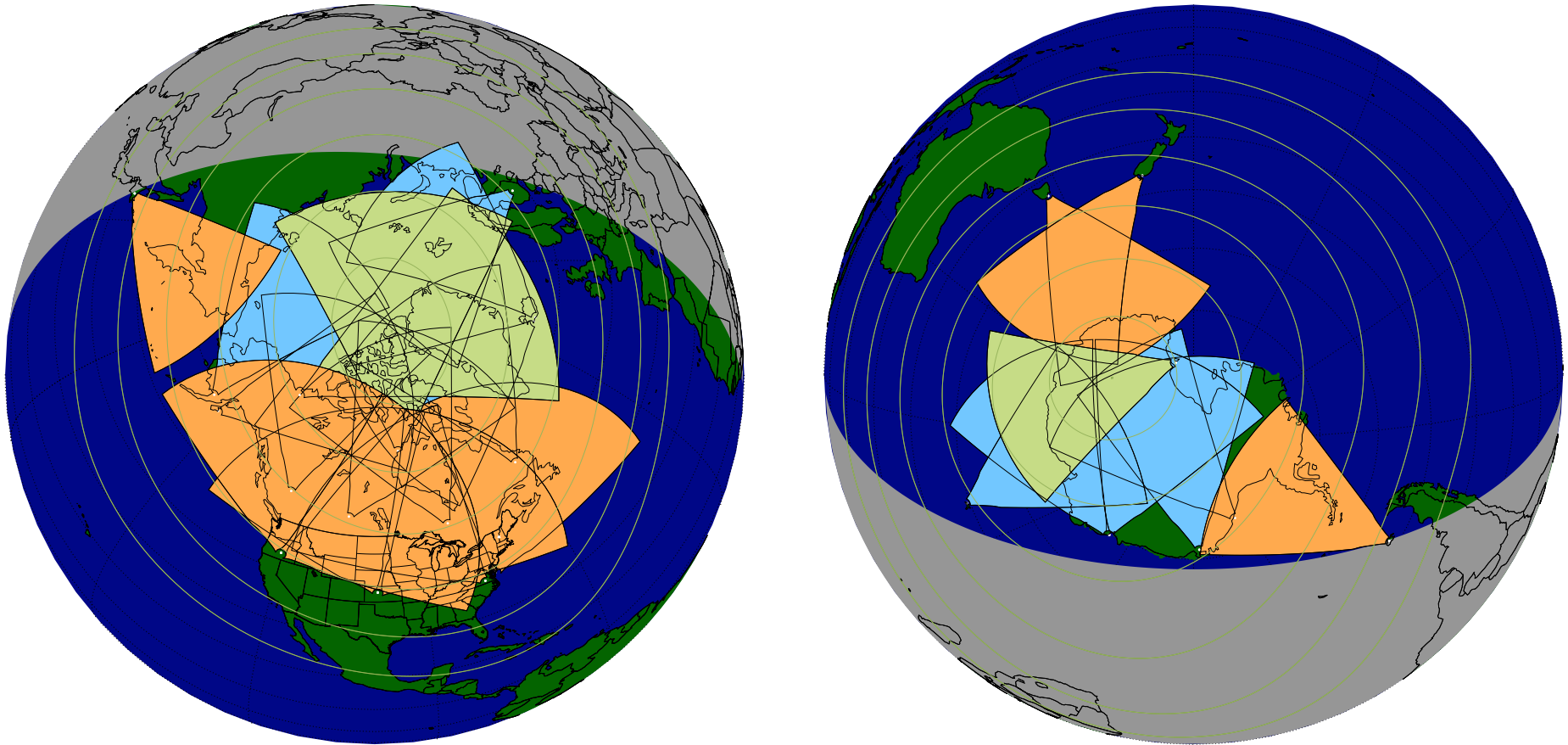


## Dartmouth College SuperDARN Radars

Under the guidance of Thayer School professor Simon Shepherd, a pair of backscatter radars were constructed in the desert of central Oregon over the Summer and Fall of 2010. These radars are funded by the National Science Foundation (NSF) and are part of an internationally funded global network of radars known as the Super Dual Auroral Radar Network (SuperDARN). There are more than 27 SuperDARN radars currently operating in the northern and southern hemispheres.

Each radar in the SuperDARN network is operated and maintained independently by the principle investigator (PI) of the given radar. Professor Shepherd is the PI for the two radars in Oregon.

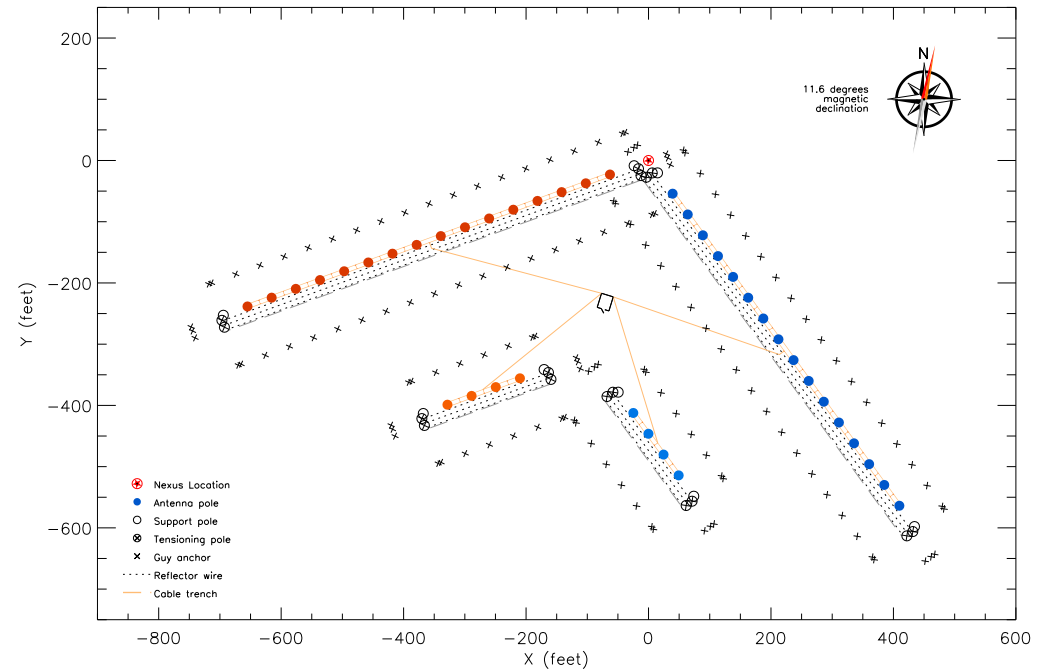


## Radar Description

A SuperDARN radar consists of two arrays of antennas; a main array that transmits and receives radio waves and an interferometer array that only receives transmissions. Each of the Oregon radar main arrays consists of 16 separate antennas and is  $\sim 715$  feet long. The overall footprint of the two radars is  $\sim 20$  acres.



View along East Main array during construction. Visible are aluminum poles, which support the antenna wires and provide tension along the array; Kevlar guying cables; conducting antenna and reflector wires; garage door springs; and a deep, narrow trench where the coaxial cables carrying the RF signals are to be buried.



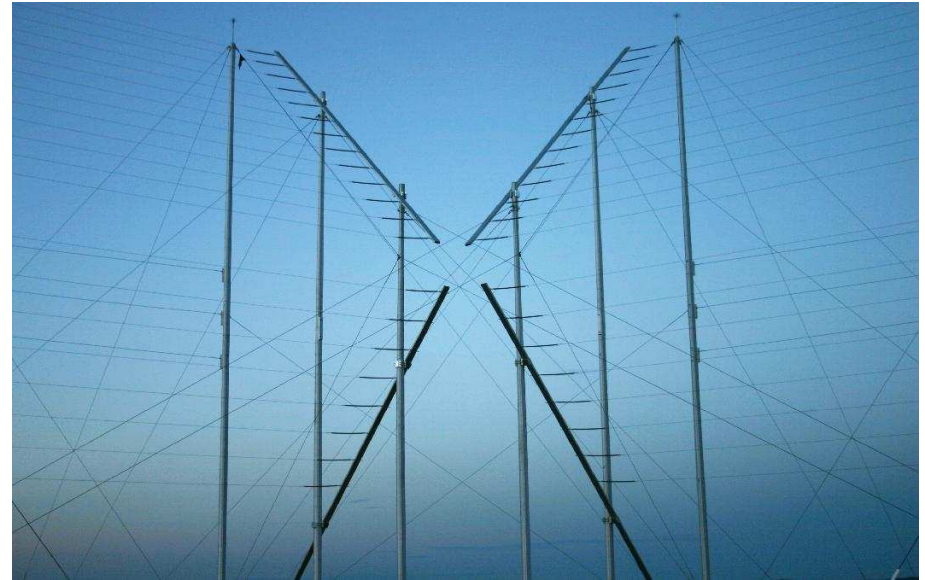
Plan view of radar site. Red dots indicate locations of antenna poles for the westward-looking radar and blue dots indicate those for the eastward-looking radar. Guying ground-anchor points are shown as  $\times$ s and a building, which houses computers and electronics, is located in the center of the two arrays.

## Radar Description

Each antenna is supported by an aluminum pole that is 56 feet tall. The poles (64 in total) are situated within  $\pm 0.5$  inches of their designed locations. The processes of assembling, erecting and tensioning the poles, and attaching antenna wires, took several months to complete with work crews consisting of students, professors and professional contract workers from Dartmouth College, Virginia Tech, the University of Alaska Fairbanks, the Johns Hopkins University Applied Physics Laboratory and Kirby Nagelhout Construction.



A large crane and heavy equipment were required during the process of erecting the poles. All 64 poles and the tensioning beams were installed in a single, long day. Tensioning and aligning the poles took several more weeks of work by several crews.



A view of the completed main arrays at the location where the two arrays converge; the Nexus. Guying cable from poles in the adjacent arrays cross in this region forming interesting geometric patterns.



## Radar Description

The radars are controlled by a single computer located in the central building. Several thousand lines of C code comprise the radar operating system which controls the operating mode of the radar, handles data acquisition and processing, storage of the data and provides a real-time data stream.

The electronics consist of two racks of transmitters per radar and a single rack of electronics shared by the radar pair. The transmitters are each capable of producing a 600 Watt radio-wave signal in the range of 8–18 MHz. The peak output of each radar is around 10 kW, but the duty cycle is only 1-2% so the average power of each radar is only about 100 W.

A phasing matrix in the central equipment rack controls the phase of the signal going to each antenna which allows the signals to form a beam that can be steered through the sky. Signal generators and additional receiver electronics are also located in the central rack.



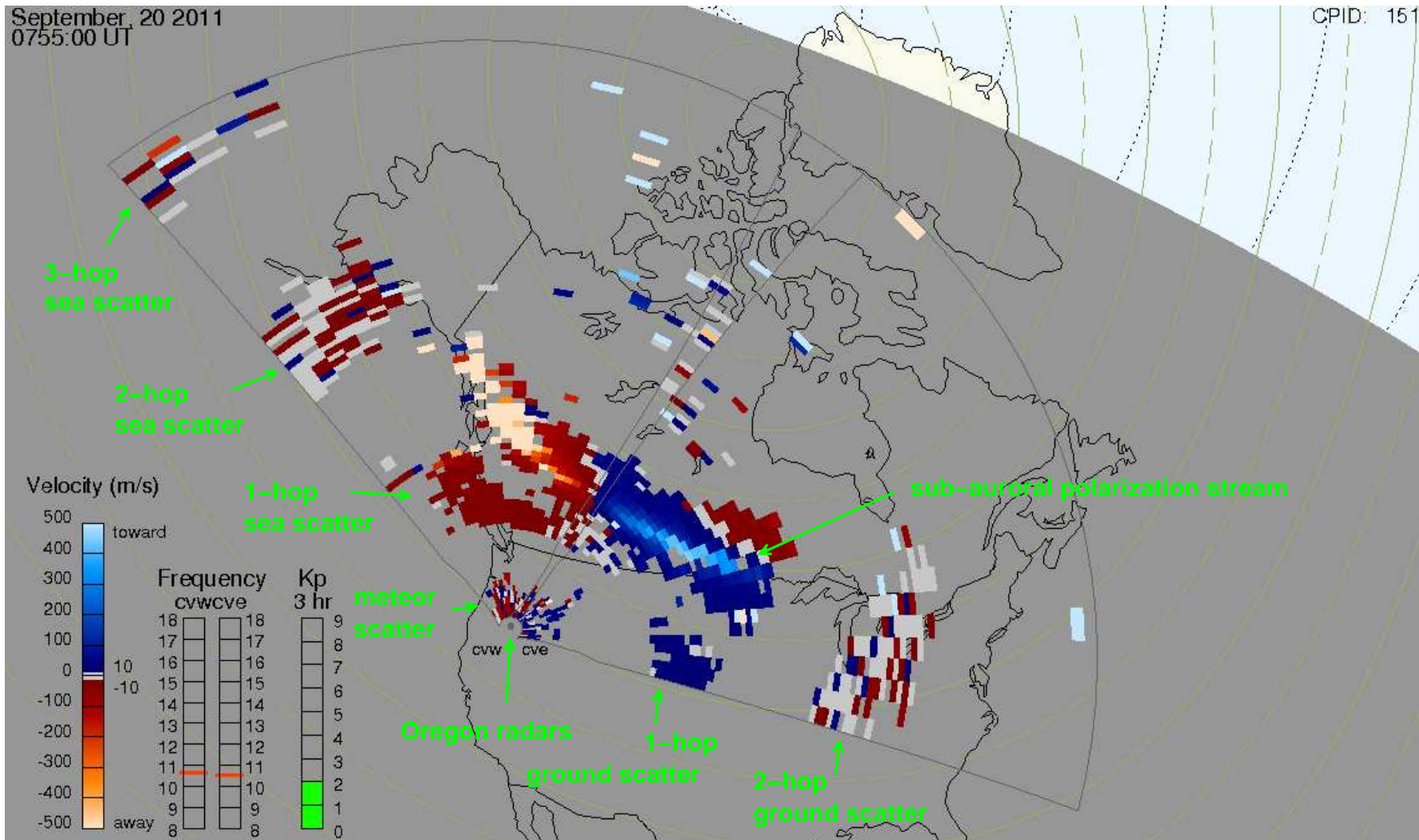
## Radar Operation

During normal operation, pulses of radio waves are transmitted from each radar in a direction forward of the antenna arrays. The signal travels up into the Earth's ionosphere where it refracts (bends). A portion of the signal is reflected from irregularities in the density of the ionosphere and travels back to the radar where they are sensed by the antenna elements. If the irregularities are moving they induced a Doppler shift in the frequency of the returning (backscattered) signal. By comparing the backscattered signal to the transmitted signal it is possible to determine the speed at which the plasma is moving. The basic principle is the same as that used by weather radar to detect motions of the atmosphere.

Because the radar signal is electronically steerable and radio waves can propagate several thousand kilometers from the radar, it is possible to measure the plasma drift in the ionosphere over a large region. The standard operating mode is to *scan* the radar over 24 beam-directions every minute providing a continuous picture of the plasma motion in front of the radar.

Radio-wave propagation is complicated by the degree of variability in the structure and composition of the ionosphere. Several modes of backscatter are observed by SuperDARN radars. The primary mode is known as  $\frac{1}{2}$ -hop backscatter where the signal travels up into the *F*-layer of the ionosphere and reflected back to the radar. Measurements of the plasma drift over 1000 km from the radar are possible with this mode. Measurements at further ranges are possible with  $1\frac{1}{2}$ -hop backscatter, where the signal bounces off the ground and back up to the ionosphere before making the return trip, or a more complicated ducting between the different layers that can form in the ionosphere.

The other primary mode of propagation is known as ground or sea scatter. In this mode the radio-wave is reflected off the ionosphere and back to the ground or sea at large distances from the radar where it then reflects back along the same path to the radar. This 1-hop mode can be especially strong over the ocean where surface roughness can strongly reflect the signal. Although this mode is generally considered as interference it is possible to detect vertical motion of the ionosphere at a distance halfway between the radar and the ground/sea scatter location. Detection of atmospheric waves propagating in and through this region are possible. When the ground or sea is especially efficient at reflecting the signal it is possible to detect 2- and 3-hop scatter where the wave continues to reflect back and forth between the Earth's surface and the ionosphere and travelling many thousands of kilometers from the radar and back.



Backscatter from the Oregon radar pair (cvw and cve) showing a strong westward flow channel across Canada. This feature known as a sub-auroral polarization stream (SAPS) and is observed by the Oregon radars during geomagnetically disturbed periods. Backscatter at close ranges to the radars is likely from meteor trails or the *E*-region. 1-, 2- and 3-hop sea scatter is observed in the most westward looking beams of cvw and the first two hops in the most eastward looking beams of cve.

## Space Weather Monitoring

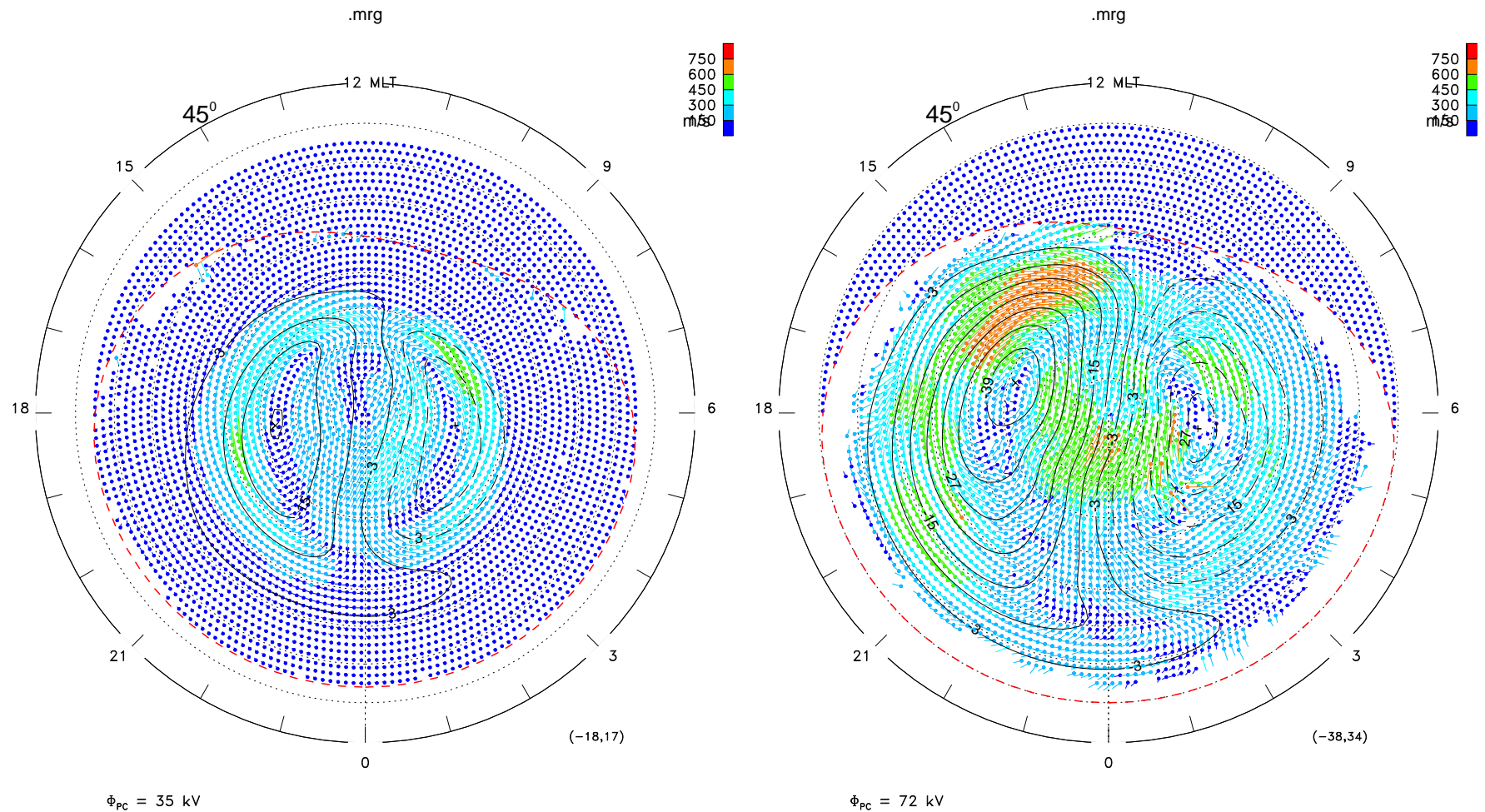
SuperDARN radars are monostatic systems and are therefore only capable of measuring the plasma motion in the line-of-sight (LOS) direction of the radar beams. In order to measure the true motion of the plasma pairs of radars are overlapped thereby giving complementary views of the plasma motion. This overlap is where the 'D', for dual, in SuperDARN comes from. The 'A', for auroral, comes from the location of the first set of radars. The auroral region is an oval shape near the magnetic poles where energy stored in the magnetosphere (the region around the Earth where the Earth's magnetic field dominates) is released and travels into the ionosphere along converging magnetic field-lines and gives rise to the beautiful light displays known as the aurora. The auroral zone is normally located above 60 degrees magnetic latitude, which is the latitude of one band of SuperDARN radars that stretch from Finland across northern Europe and Canada all the way to Alaska.

The real strength of SuperDARN radar network is that while each radar is maintained and operated by PIs throughout the world, each radar conforms to a common operation schedule and data format. By working in this cooperative mode the data from all the radars can be combined together to provide a synoptic map of the plasma motion in the Earth's polar regions. Because plasma motion is driven by electric fields that are communicated along magnetic field-lines, the motion of the plasma in the ionosphere provides a view of the motion of plasma in the larger magnetosphere. This view allows scientists to study the electromagnetic coupling between the solar wind and the Earth's magnetosphere. For this reason the network of SuperDARN radars is an important and unique tool in the study of space weather and space climatology.

One aspect of space weather that is of particular interest is the response of the magnetosphere-ionosphere system during geomagnetic storms; disturbances in the geospace environment that are caused by explosions on the surface of the Sun which expel mass and energy that travel through interplanetary space and impact the Earth's magnetosphere. During these storms the auroral region, and the zone of plasma motion or convection, moves equatorward. To view this expanded convection zone radars must be situated at latitudes further from the Earth's magnetic poles. The Oregon radars are located at such latitudes and are part of a second layer of radars that extend the coverage of the auroral radars to lower latitudes so that they can make observations of plasma motion during geomagnetic storms.



## Space Weather and Climatology



Maps of the convecting plasma shown for a period of low and high geomagnetic activity. The strength of convection is shown by colored telldaes that indicate flow direction and speed according to the color-scale. Contours indicate the electric potential associated with the plasma motion. The strength of the electric potential is 35 kV and 72 kV for the quiet and disturbed period, respectively, indicating a stronger coupling to the solar wind in the latter case. The importance of the mid-latitude radars, such as those in Oregon, can be seen in the disturbed period as convection expands equatorward of 60 degrees magnetic latitude where the first layer of SuperDARN radars is located.