SuperDARN

What is it?
How does it work?
Where is it going?

Kile Baker

Ionospheric radars

Incoherent Scatter radars

AMISR

Arecibo Observatory

Sondrestrom Radar

Coherent scatter radars

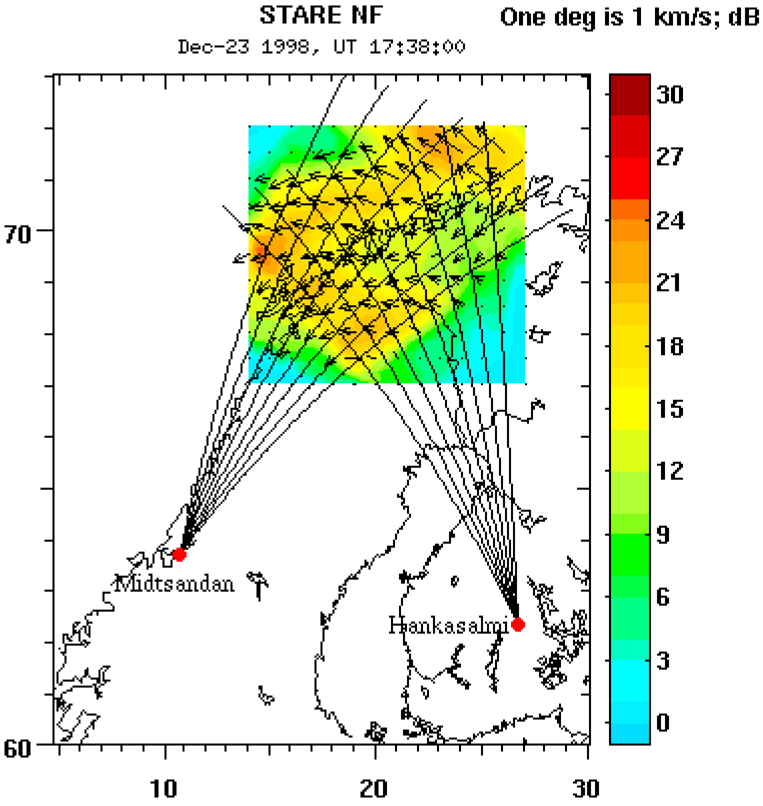
STARE – Scandinavian Twin Auroral Radar Experiment (~1978)

Goose Bay Radar (~1990)

Christmas Valley SuperDARN radars (2011)

Brief history of coherent scatter radars

- STARE = Scandinavian Twin Auroral Radar Experiment
  - VHF, fixed frequency
  - Only sensitive to plasma irregularities in the auroral E-region
- OPEN → ISTP/GGS
  - NASA mission that encouraged ground-based and theory as part of the mission
  - DARN = Dual Auroral Radar Network



DARN → SuperDARN

- Set up pairs of STARE type radars spread across Canada and Alaska.
- Include STARE and add additional VHF pair in the UK and Sweden (SABRE)
- OPEN was delayed and descoped. During the delay the DARN concept was changed from VHF to HF.

Early SuperDARN

- Several experiments by French researchers (C. Hanuise, J-P. Villain, et al.) using HF frequencies demonstrated that an HF radar could be built.
- Ray Greenwald and J-P Villain set up a 4-antenna, HF system in Alaska (very near where AMISR now is located) in 1982.
  - This is where I come into the picture.
  - The experiment was successful but it was clear a 4-antenna system would not have the spatial resolution nor the sensitivity needed for serious scientific work.

Goose Bay

- The concept moved from 4 antennas to 16, with separate transmitters on each antenna.
- With 16 antennas it was possible to generate 16 separate beams by controlling the phase of the HF transmission (and reception) at each antenna. Electronic control of the phase meant that the beam selection could be done virtually instantaneously.
- Still no funding from OPEN/ISTP. Initial funding for the radar came from AFOSR.
- Radar was built and became operational in October, 1983.

1984-1988

- In partnership with British Antarctic Survey the concept was to construct two pairs of radars with conjugate fields of view.
    - Goose Bay + ? in the northern hemisphere
    - Halley Station + Siple Station in Antarctica.
        - Siple was closed before radar could be built
    - Still no funding from NASA so second radar in N. hemisphere put on hold.
    - Halley radar built in 1987/88
        - Jointly funded by BAS and NSF

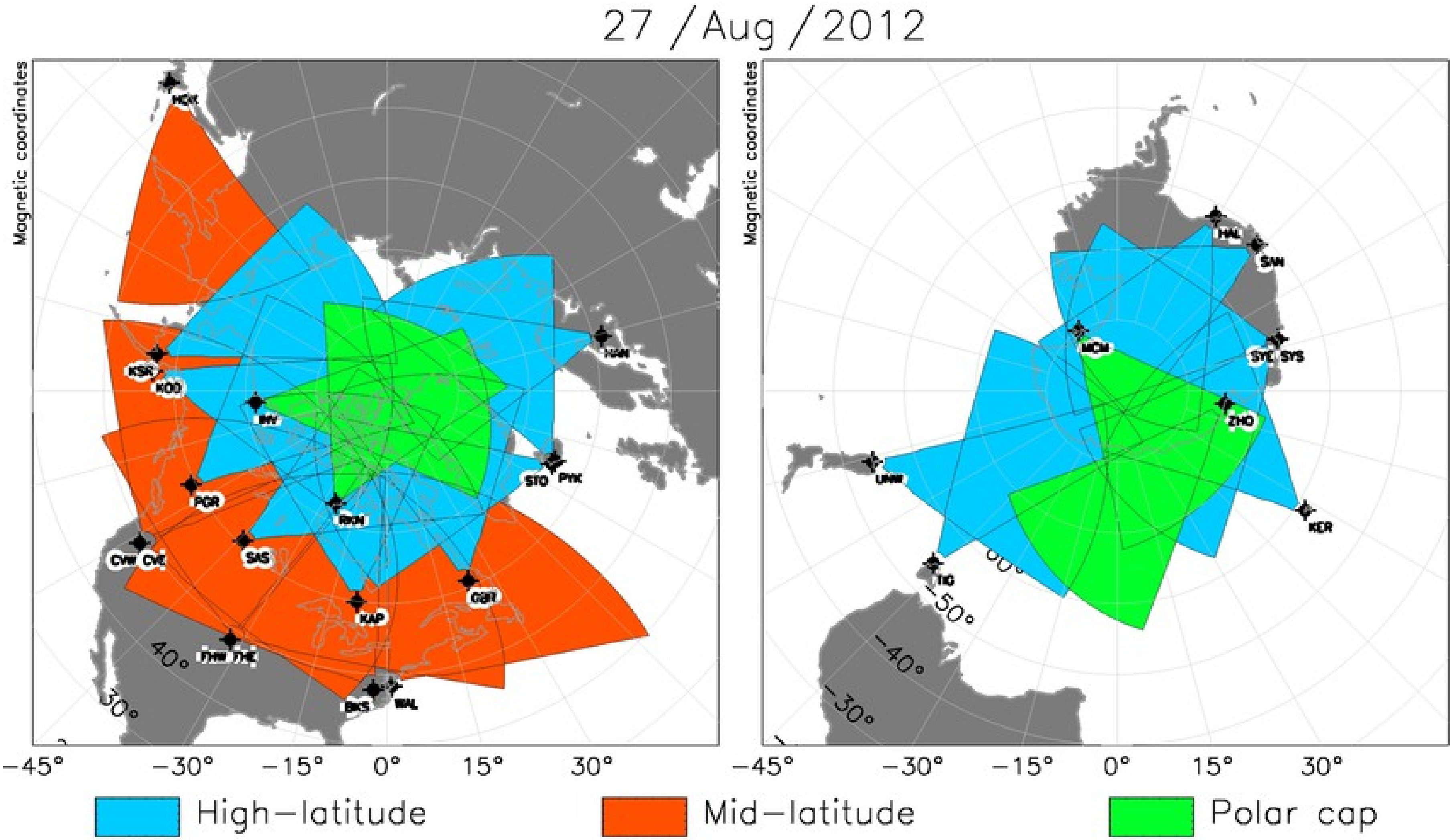
Finally some NASA funding

- OPEN morphed into ISTP/GGS
  - Funding for ground-based activities was substantially reduced. We had enough money to build second N. Hemisphere radar at Kapuskasing, Ontario.
- Siple was closed but the South African's were interested in building a second S. Hemisphere radar at their base, SANAE.
  - Jointly funded by NSF and S. Africa.
  - U.S. Funding had to wait until the end of apartheid.

Improvements

- Various improvements have been made to the radars over the years
  - Addition of interferometer array
    - Determine angle of arrival of backscattered signal
    - Improves the determination of geographic location
  - Increased transmitter power
    - Initially we could only transmit 400 W at each antenna
    - New radars transmit 1000 W at each antenna
  - Increased data storage
  - Real-time analysis of the data
  - Real-time transmission of data from the radars to the home institutions.

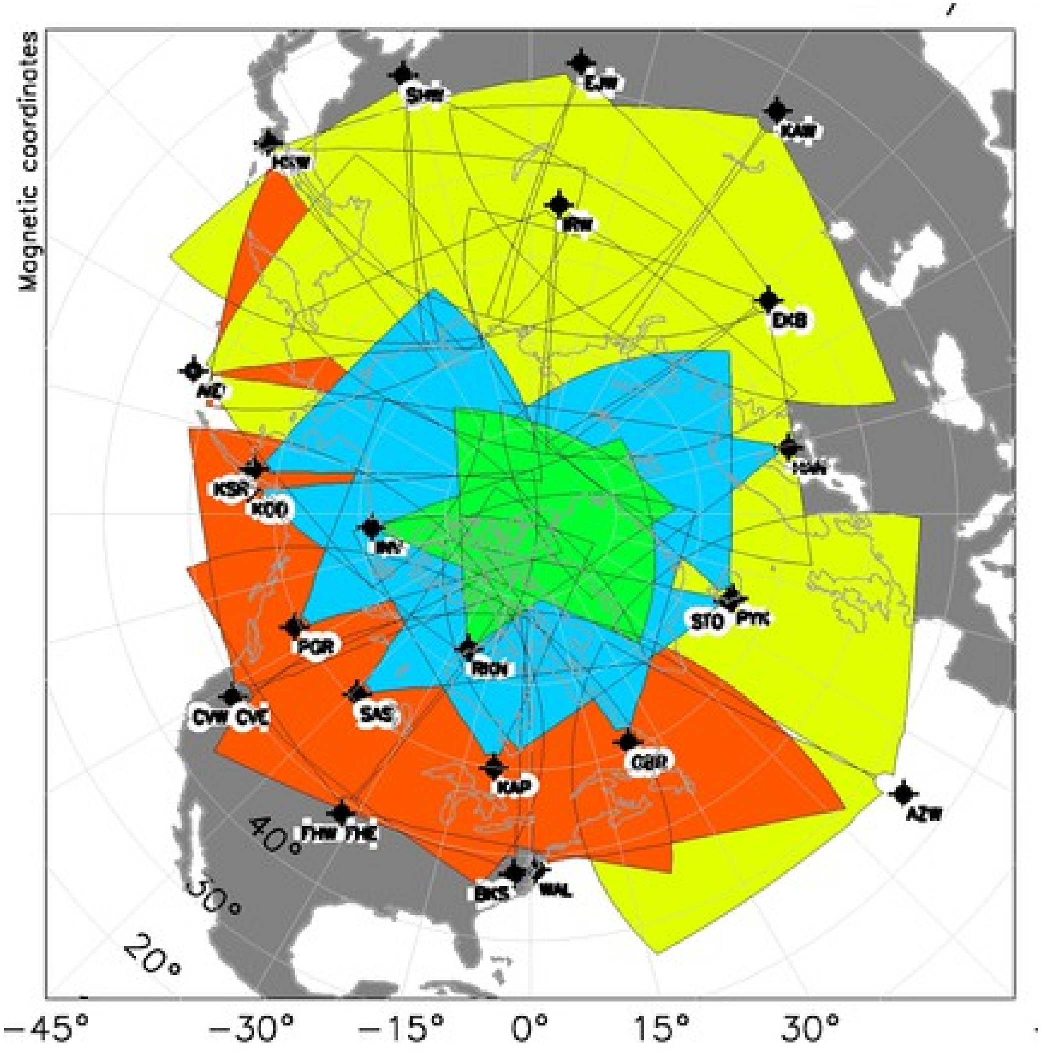
Current state of SuperDARN



Operations

- Each radar runs continuously, 24 hours/day
- In most cases the radars generate a complete scan across the field-of-view in **one minute.**
- Fields-of-view have been extended in range to cover 3000 km.
- Most of the radars are able to send a selection of data to home institutions in real-time.
- JHU/APL collects all the real-time feeds and generates real-time data products for space weather use.

Future state?



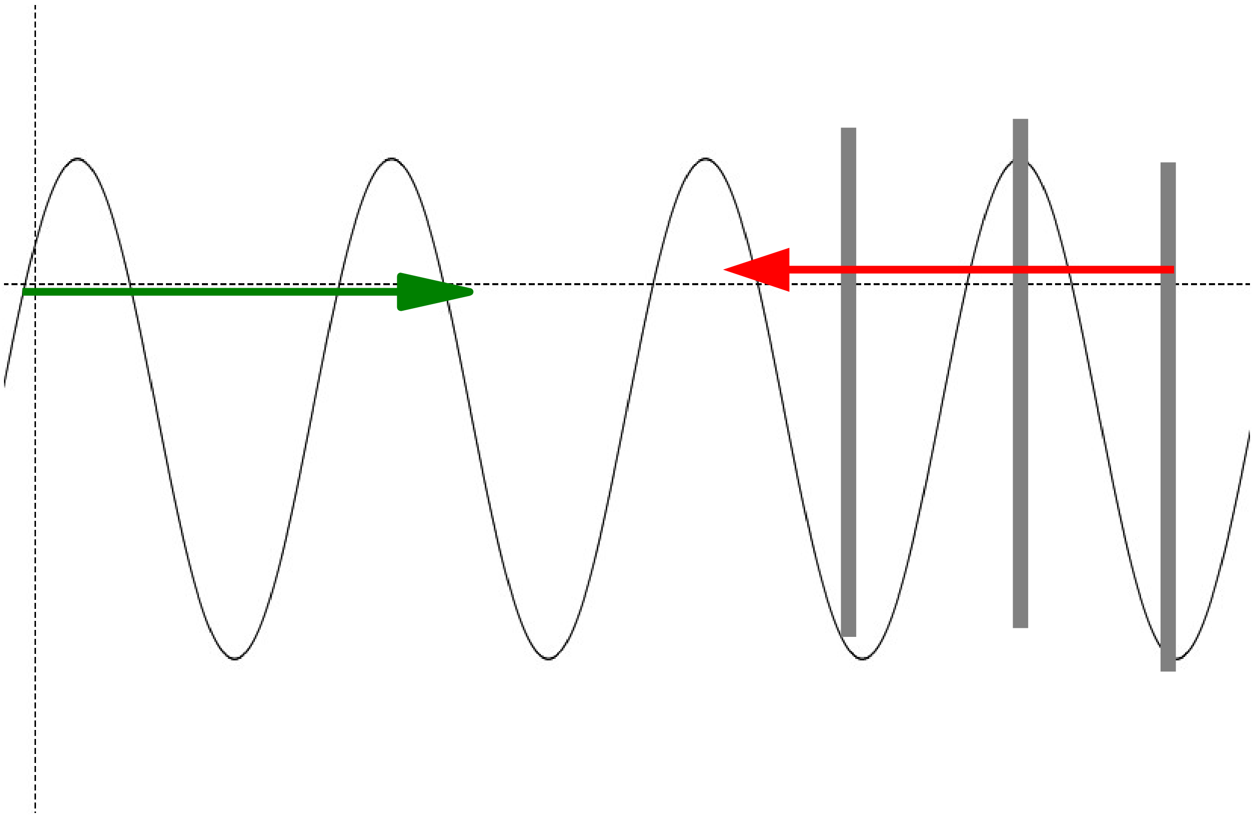
Personnel from U. Alaska are in Adak right now seting up a new pair of radars.

Funding for Azores radars is in place but site selection not yet complete.

Ionospheric Irregularities

- Field-aligned
  - Plasma can move freely along magnetic field. Density irregularities quickly disappear in the parallel direction
- Irregularity structures are frozen in to the ambient plasma and move with the ambient plasma.
  - In the F-region the plasma convects due to the E cross B drift. Thus a radar measuring motion of the irregularities is measuring the local electric field.

Coherent backscatter



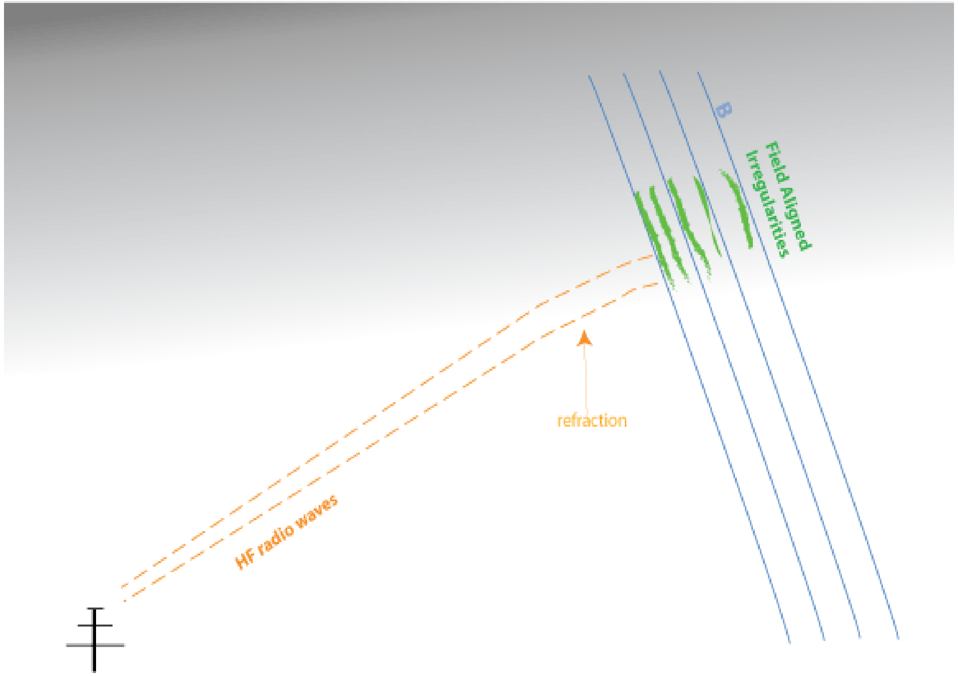
When spacing of irregularities = λ/2 scatter of the signal in the backwards direction results in constructive interference. The result is a strong backscattered signal (similar to Bragg scattering in a crystal)

A problem with VHF radars

- Because irregularities are field-aligned, in order to get coherent backscatter, the transmitted wave must interact with the irregularities where the k vector is perpendicular to the magnetic field.
- VHF waves are essentially unrefracted by the ionosphere.
  - The only place where the k vector is perpendicular to the field is in the auroral E-region.

Advantage of HF radar

- HF signals are strongly refracted by the ionosphere and are often reflected back toward the earth.
- As a result, the wave can become perpendicular to the field over a wide area of the F-region.



Basic characteristics of a SuperDARN radar

- Uses pulses, not continuous wave transmission
- Uses phase-locked receiver
  - This means that the phase of the received signal can be compared with the phase of the transmitted signal.
  - The result is two outputs from the received, I and Q.
    - The I component is the signal in-phase with the transmitted phase.
    - The Q component is the signal at 90 degrees to the transmitted phase.

Measuring velocity with double pulse

- If the target is stationary then the phase of the received signal from the first pulse will be the same as the phase of the received signal from the second pulse.
- If the target is moving then the two phases will be different and the amount of difference is proportional to the velocity of the target.

Double-pulse ACF

Let S1 be the complex signal received from pulse 1 and let S2 be the signal from the second pulse.

$$S_1 = A_1 exp\,(i\varphi_1)$$

$$S_2 = A_1 \exp\,(i(\varphi_1 + \omega\tau))$$

The 0th lag of the autocorrelation function is R0.

$$R_0 = S_1 S_1^* = A_1^2$$

The first lag of the ACF is R1

$$R_1 = S_2 S_1^* = A_1 \exp\,(i(\varphi_1 + \omega\tau))(A_1 exp\,(-i\varphi_1) = A_1^2 exp\,(i\omega\tau)$$

Note that the random phase has canceled out.

What if we use three pulses?

This is somewhat modified from our previous picture. Here, we have backscattered signals from an extended range of irregularities.

$$R_1 = S_3 S_2^*$$

No random phase

$$R_1 = A^2 e^{i\omega_1\tau} + B^2 e^{i\omega_2\tau} +$$

$$AB[e^{i(\varphi-\vartheta+2\omega_1\tau)} + e^{i(\vartheta-\varphi+\omega_2\tau-\omega_1\tau)}]$$

$$ACe^{i(\xi-\varphi-\omega_1\tau)} + BCe^{i(\xi-\vartheta)}$$

With scatter coming from multiple ranges the random phases no longer cancel exactly.

BUT, if we send out a sequence of triple pulses the random phases will be different for each set of triple pulses. When we add them all together the random phases will tend to cancel.

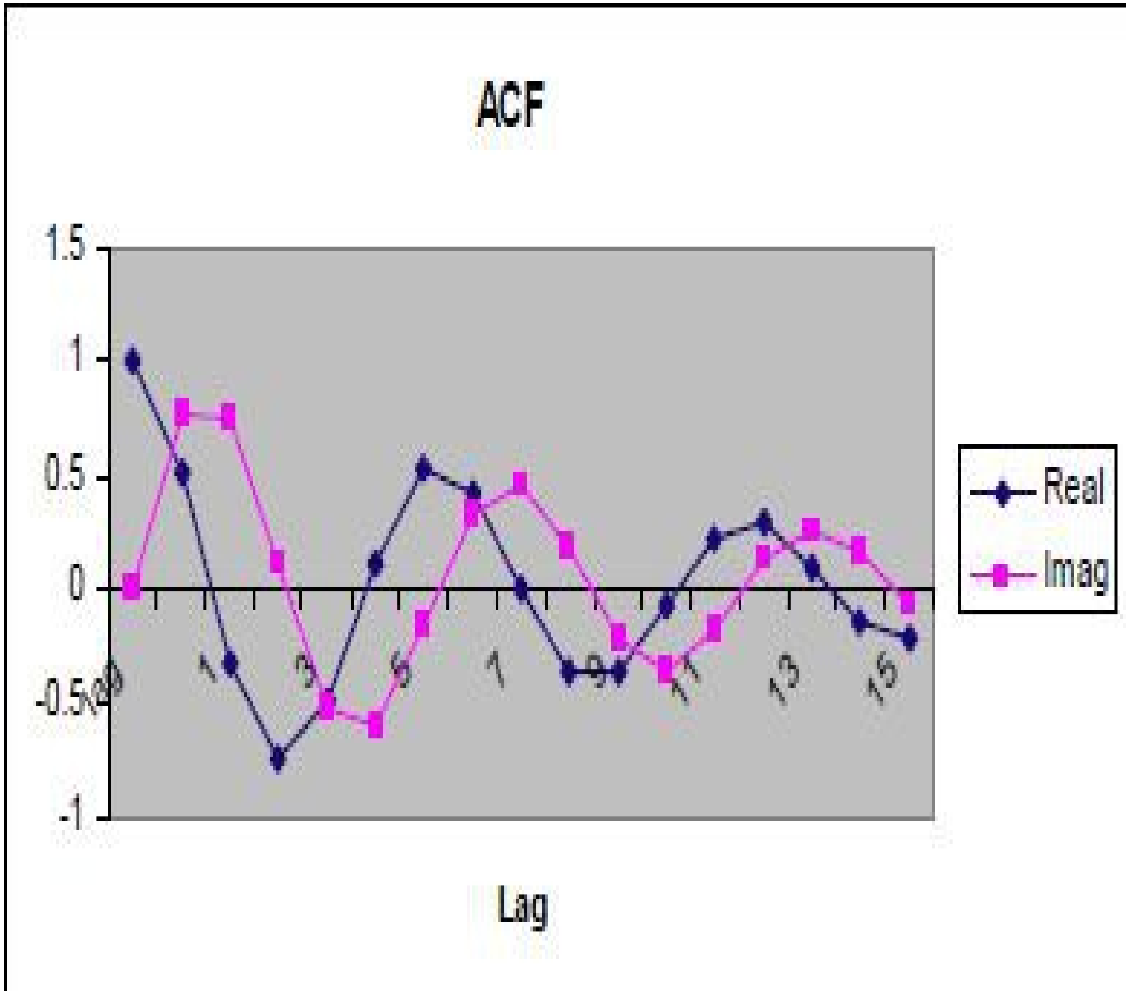
The range aliasing problem

- When we add up a large number of pulse sequences the random phases tend to cancel and we can ignore those terms.
- However, there are terms that have no random phase and yet have mixes of signals from two different locations in the ionosphere.
  - This is the range aliasing problem
  - We can fix it (at least partly) by using a multi-pulse pattern instead of a simple repeating pulse.

Multipulse pattern

Here we can only get the first lag of the ACF from the first two pulses. We get a second lag from the second and third pulse and we get a third lag from the first and third pulses.

What does an ACF look like



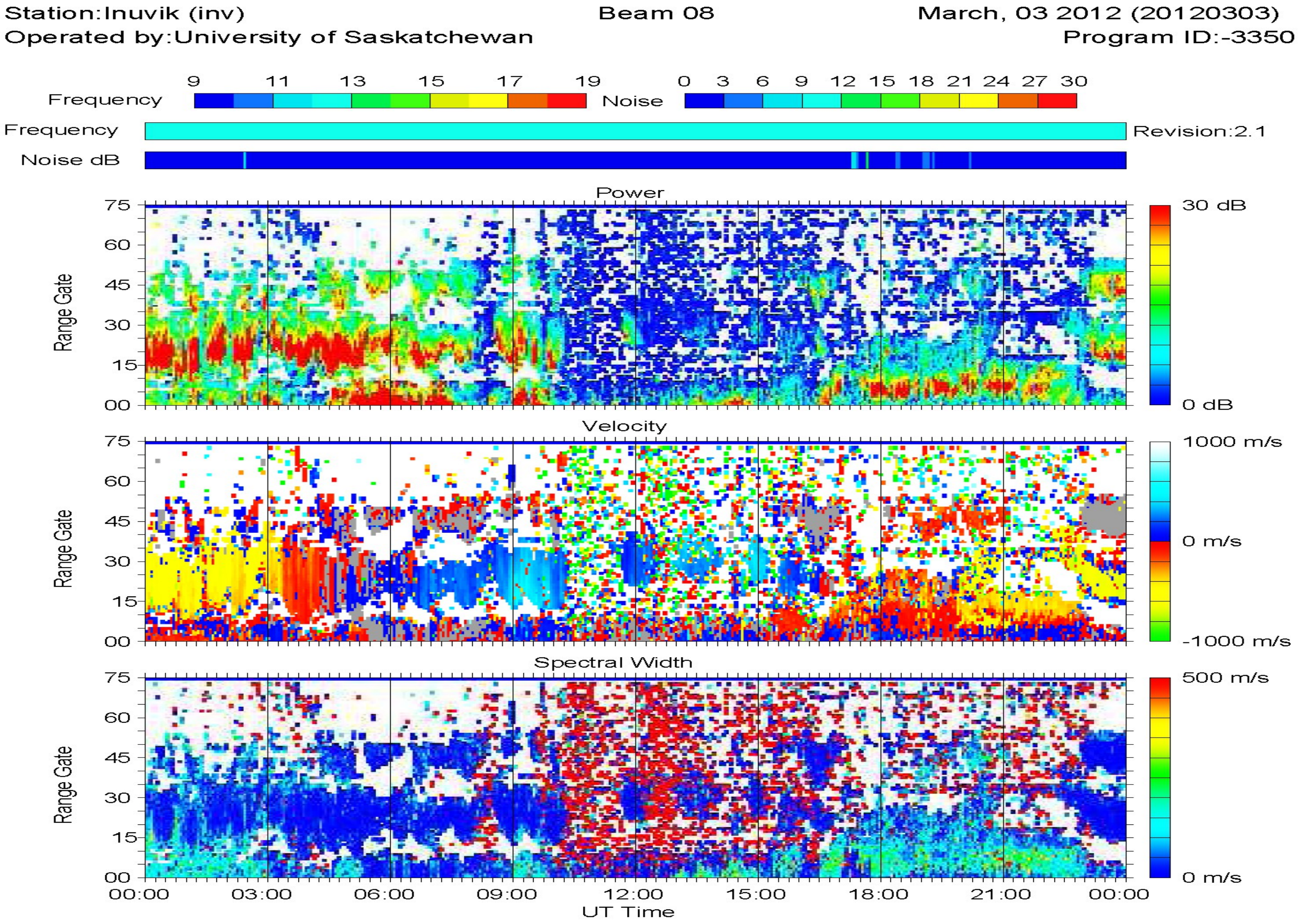
Note that the real and imaginary components are in quadrature (i.e. 90 degrees out of phase).

Note also that the amplitude decreases with lag.

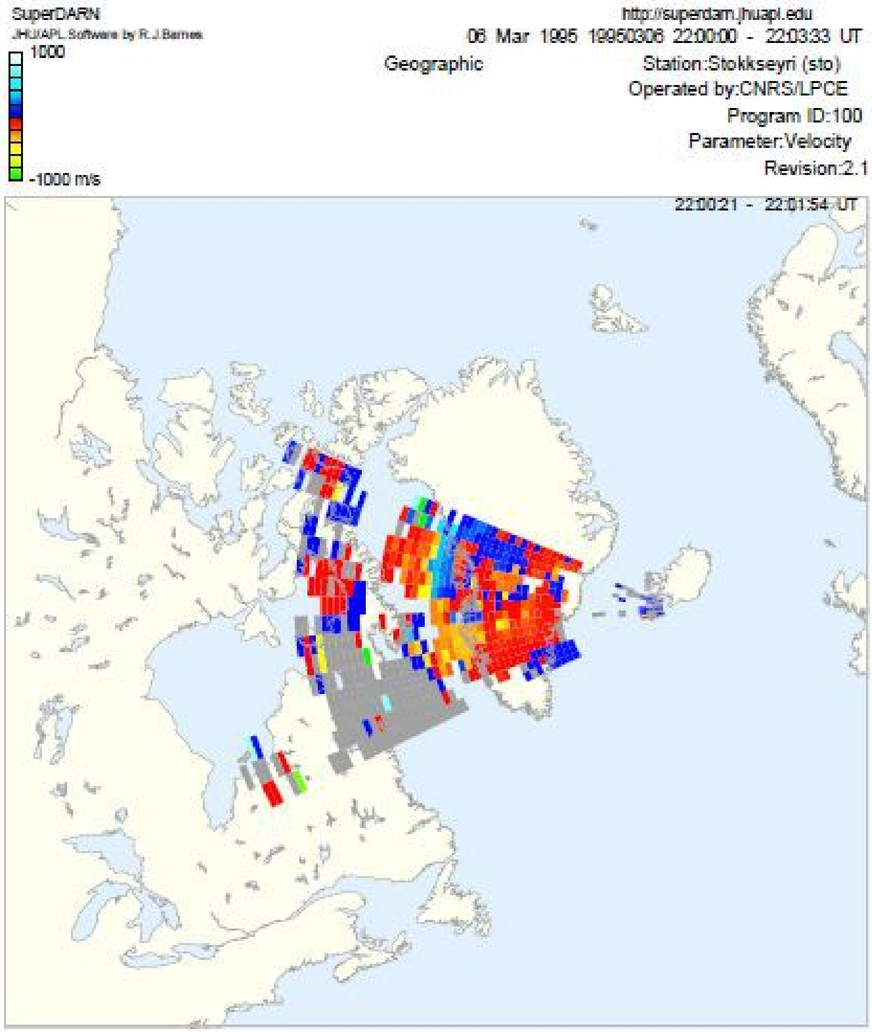
The frequency of the ACF gives you the velocity of the moving plasma.

The decrease in amplitude of the ACF is related to the width of the Doppler power spectrum. Faster decay of the amplitude implies a wider spectrum.

Range-time plots



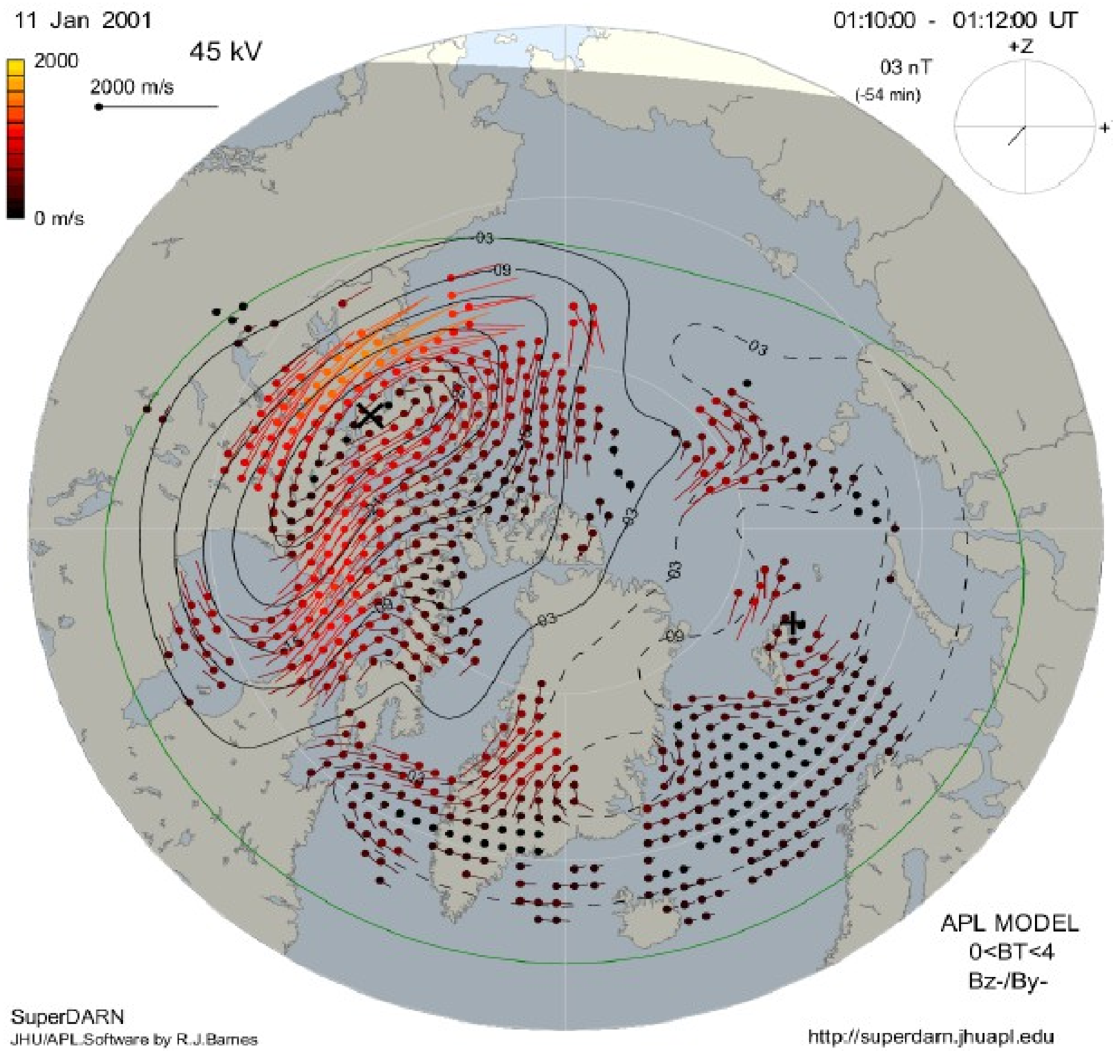
Field-of-view scan plots



Combining radars to get convection maps

- You can only get directly measured vectors when two radars have an overlapping field of view AND both radars are seeing backscatter from the same geographical location.
  - When these conditions are met that's when we have the highest quality data and the least ambiguity.
  - Restricting the global analysis of convection to directly overlapping observations eliminates a large amount of data.
- Map-Potential:To use all the available data:
  - Expand the polar cap potential in terms of spherical harmonics.
  - Fit the complete set of line-of-sight velocities to determine the coefficients of the polar cap potential.

Example of result from Map Potential



Topics that have been and can be investigated using SuperDARN

- Plasma physics of ionospheric irregularites and the associated instabilities
    - Instabilites that form irregularities
    - Sources of turbulence in ionospheric structures
    - Generating irregularities artificially (heating experiments)
- Conjugate behavior
    - Variations in ionospheric potential between hemispheres
    - Convection structures associated with conjugate auroral forms.
- Polar cap potential drop as a function of IMF and solar wind speed and density
    - Polar cap potential saturation
    - Dynamics of polar cap potential (convection pattern) during changes of IMF

- Gravity waves and traveling ionospheric disturbances
  - Large scale (global) observations of propagation
  - Generation of TIDS by auroral activity
- Field-aligned currents
- Ionospheric conductance
- Neutral winds and tides (using scatter from meteors)
- Storms and substorms
- Geomagnetic pulsations

Using SuperDARN in conjunction with other data sources

- Use SuperDARN to get global structure and ISRs to look at plasma conditions in specific areas within the global structure.
- Ground-based magnetometers
- AMPERE global field-aligned current data
- Satellites
  - DMSP, THEMIS, CLUSTER, RBSP, ACE, WIND, POLAR, FAST, . . .
- MHD simulations

Future directions for the radars

- New radars to be built in the Aleutian Islands, the Azores, South Africa and Antarctica
- Possibly new radars in Russia and China
- Improvements to the radars
  - STEREO mode
  - Multi-frequency mode
  - Improved spatial and temporal resolution

Some new research topics

- Generate new convection models using multi-linear regression analysis of the coefficients in the expansion of the ionospheric potential.
- New operating modes to eliminate missing and bad lags in the ACFs
- New operating modes that generate power spectrum directly, bypassing the ACF analysis
- Improvements to determination of geographical location of backscattered signal

More research areas

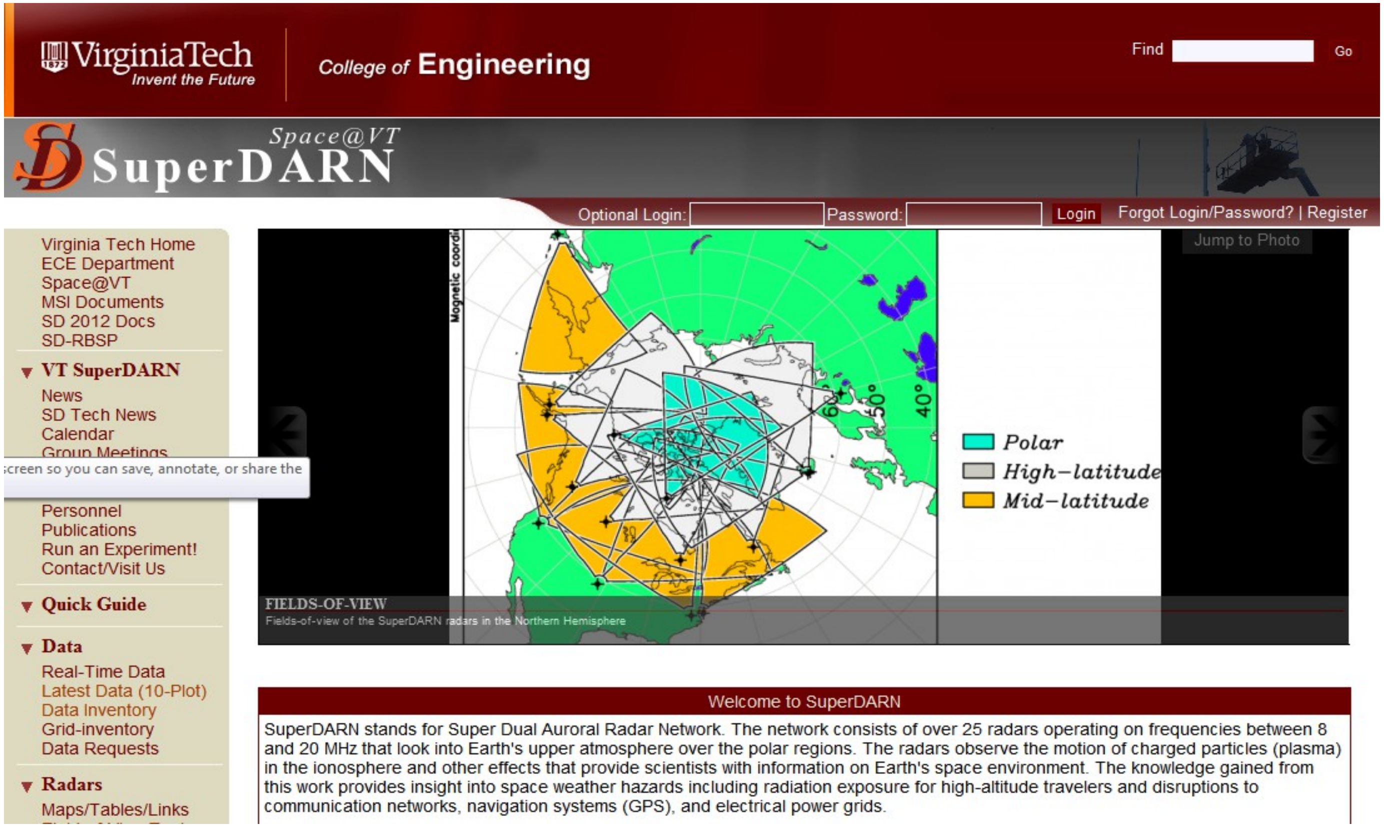
- Doppler power spectra. What determines spectral width and shape?
  - Most spectra appear to be Lorentzian in shape but some a Gaussian shaped and some spectra contain multiple peaks.
  - Should we characterize spectral with in terms of the velocity or in terms of frequency
    - If spectral width is due to distribution of scatterers moving with sllightly different velocities then changing the radar frequency should affect the width when measured in velocity.
    - But in many situations changing the radar frequency leaves the spectral width unchanged when measured in frequency.

New topic that has just been funded

- Using SuperDARN convection observations as the “ground truth” for MHD data assimilation technique
  - New method for directly assimilating AMPERE data into an MHD code (LFM code)
    - Data assimilation technique being developed at UCLA (D. Kondrashev)
    - Implimentation of the assimilation technique into the MHD model being done at JHU/APL
    - Event selection and comparison with SuperDARN data at GMU

Web sites for SuperDARN

- Http://superdarn.jhuapl.edu
- http://vt.superdarn.org/tiki-index.php



FIELDS-OF-VIEW
Fields-of-view of the SuperDARN radars in the Northern Hemisphere

Welcome to SuperDARN

SuperDARN stands for Super Dual Auroral Radar Network. The network consists of over 25 radars operating on frequencies between 8 and 20 MHz that look into Earth's upper atmosphere over the polar regions. The radars observe the motion of charged particles (plasma) in the ionosphere and other effects that provide scientists with information on Earth's space environment. The knowledge gained from this work provides insight into space weather hazards including radiation exposure for high-altitude travelers and disruptions to communication networks, navigation systems (GPS), and electrical power grids.