Circumterrestrial space processes as observed by the **S**uper **D**ual **A**uroral **R**adar **N**etwork

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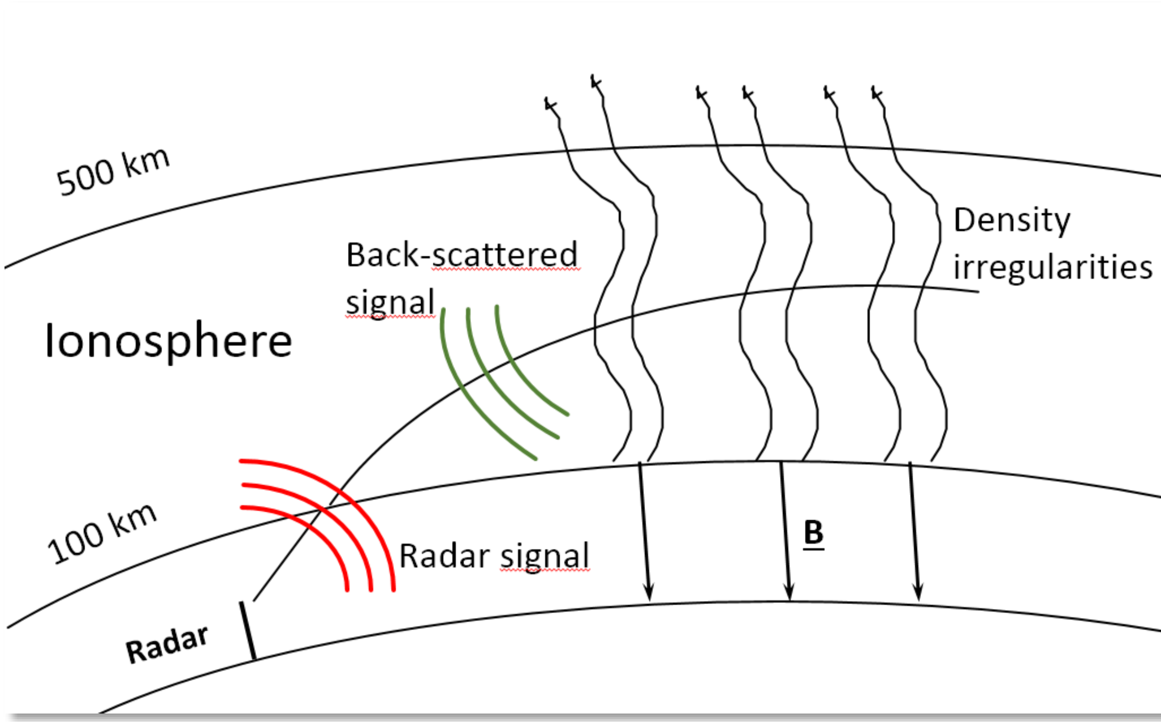
INAF-IAPS

work from the SuperDARN community

ISSS – L'Aquila, 6 June 2016

SuperDARN – principles

The Super Dual Auroral Radar Network continuously measures ionospheric convection in the southern and northern mid/high latitudes and polar caps (Chisham et al., 2007 and reference therein).



HF radars signals are refracted in the ionosphere, become roughly perpendicular to the local magnetic field lines and are back-scattered by field aligned decameter scale (1/2 the radar wavelength ~20 m) irregularities of the electron density.

SuperDARN – principles

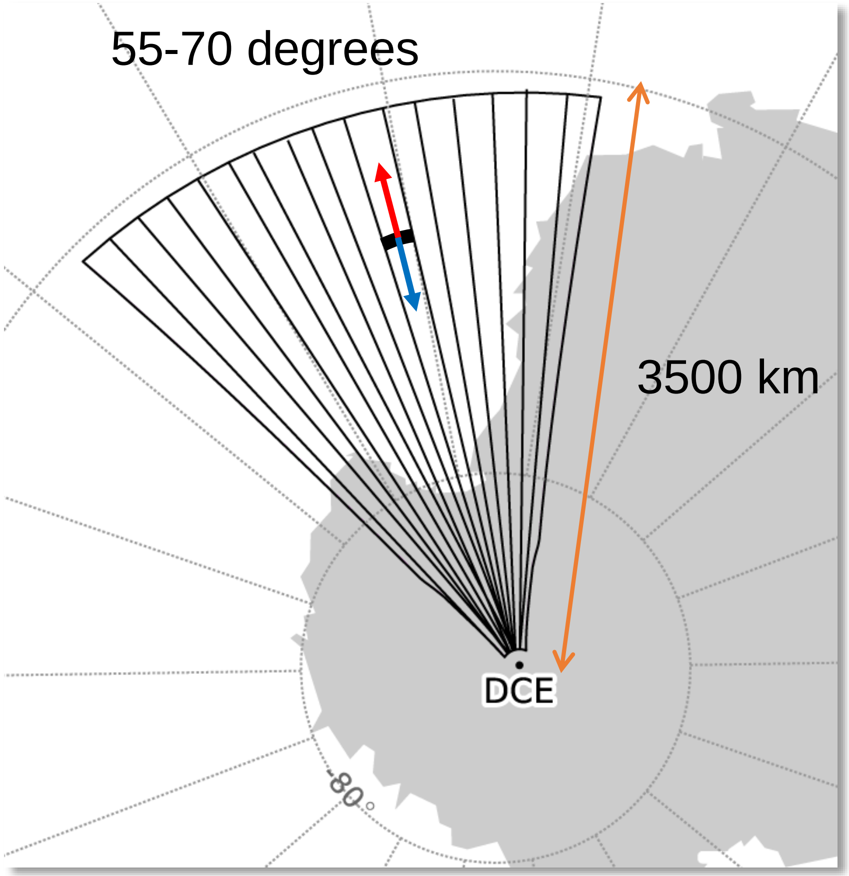
A phased array of antennae is used to steer the signal in **16** (or more) **beam directions**

Multi-pulse sequences are used to produce the autocorrelation function (ACF) of the backscattered signal at each **range gate** and compute:

- The power of the backscattered signal (Signal to Noise Ratio)
- The width of the Doppler power spectrum
- The mean Doppler velocity: the line-of-sight component of the F-region plasma drift velocity.

75 range gates with **45 km** resolution
Total Field of View: **1200** range – beam cells

Time resolution for a complete scan:
1-2 minutes.



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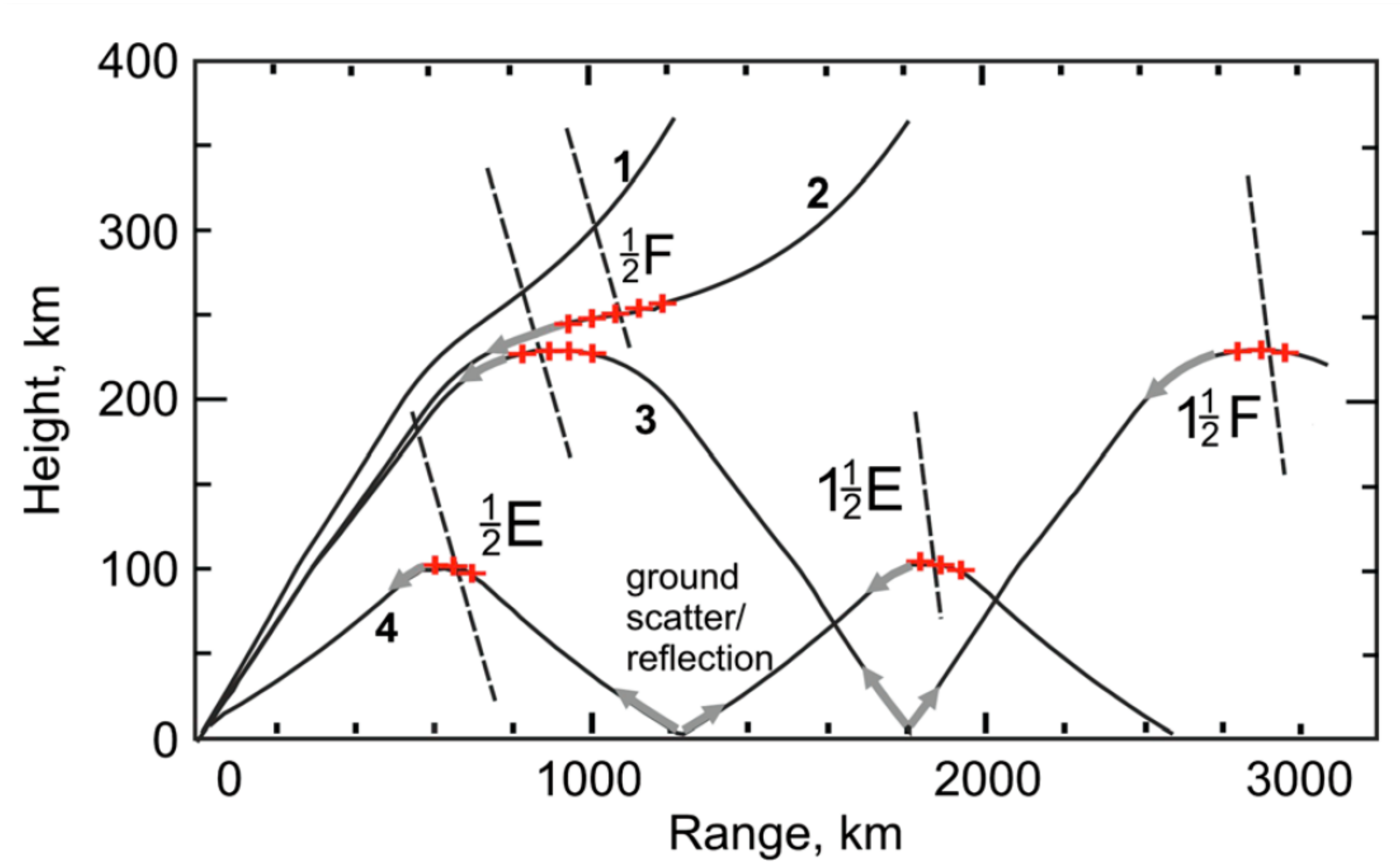
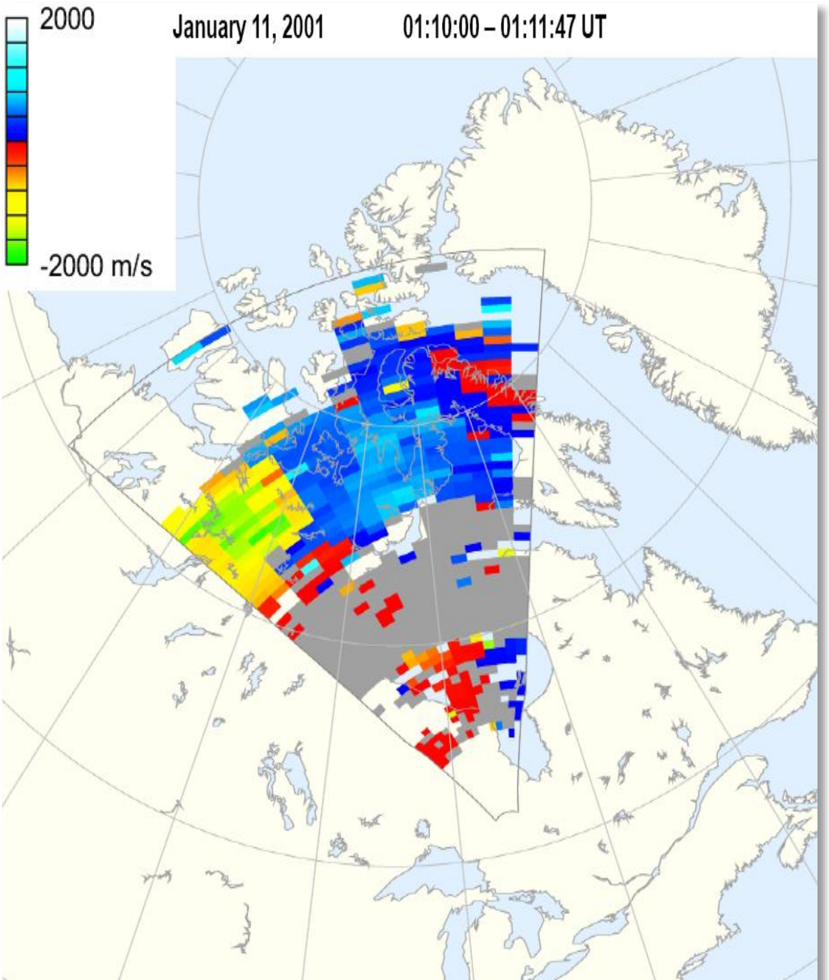
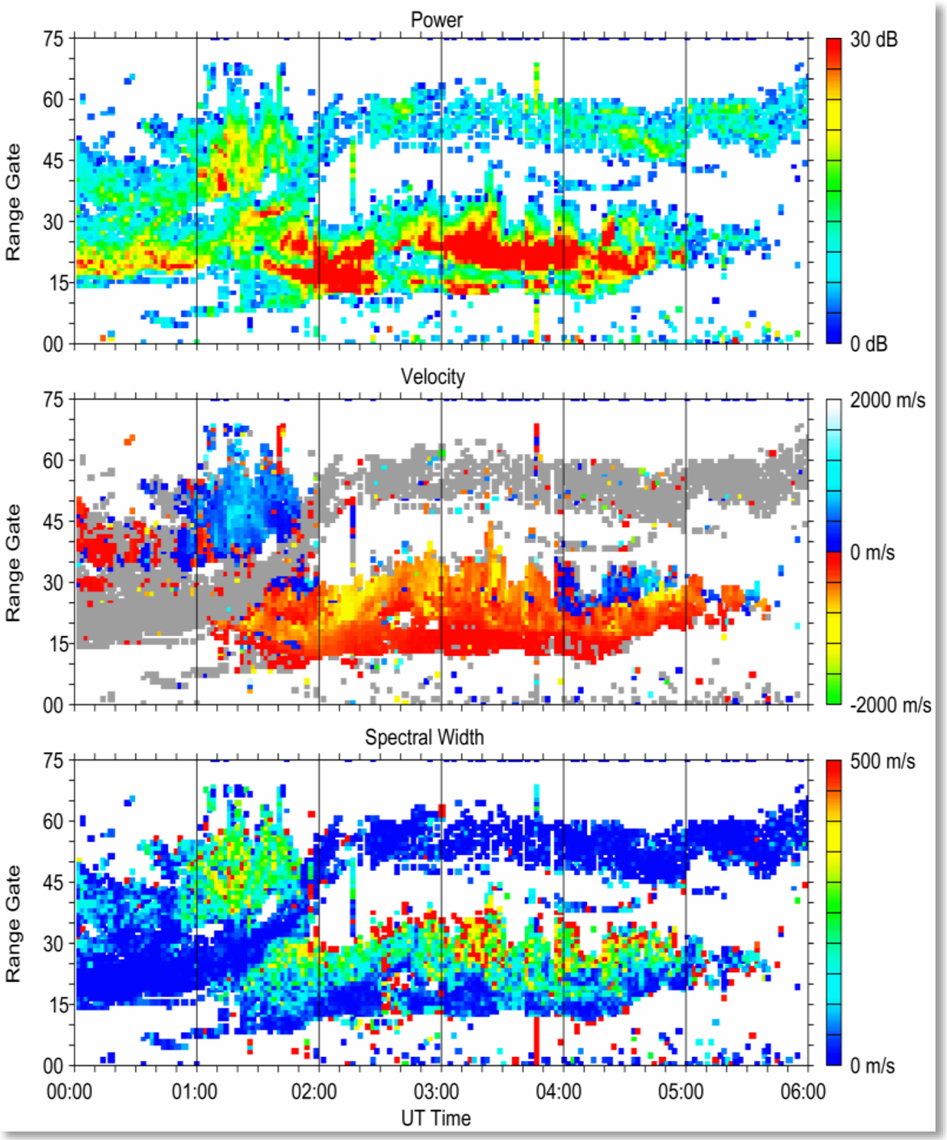
SuperDARN – ground scatter



SuperDARN – Field of View and Range Time Plot



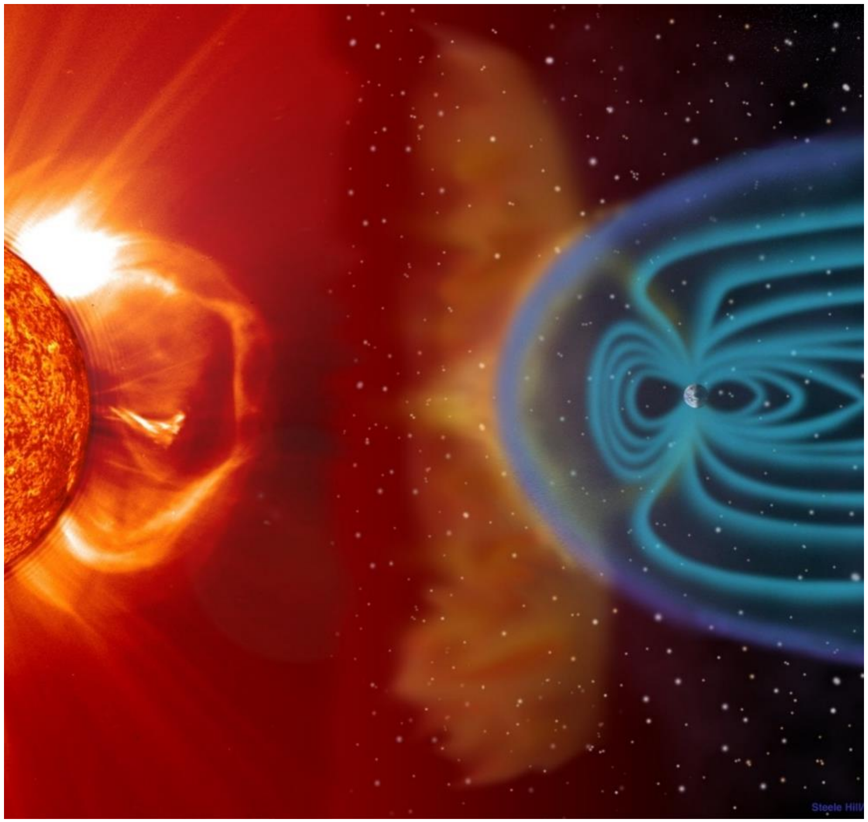


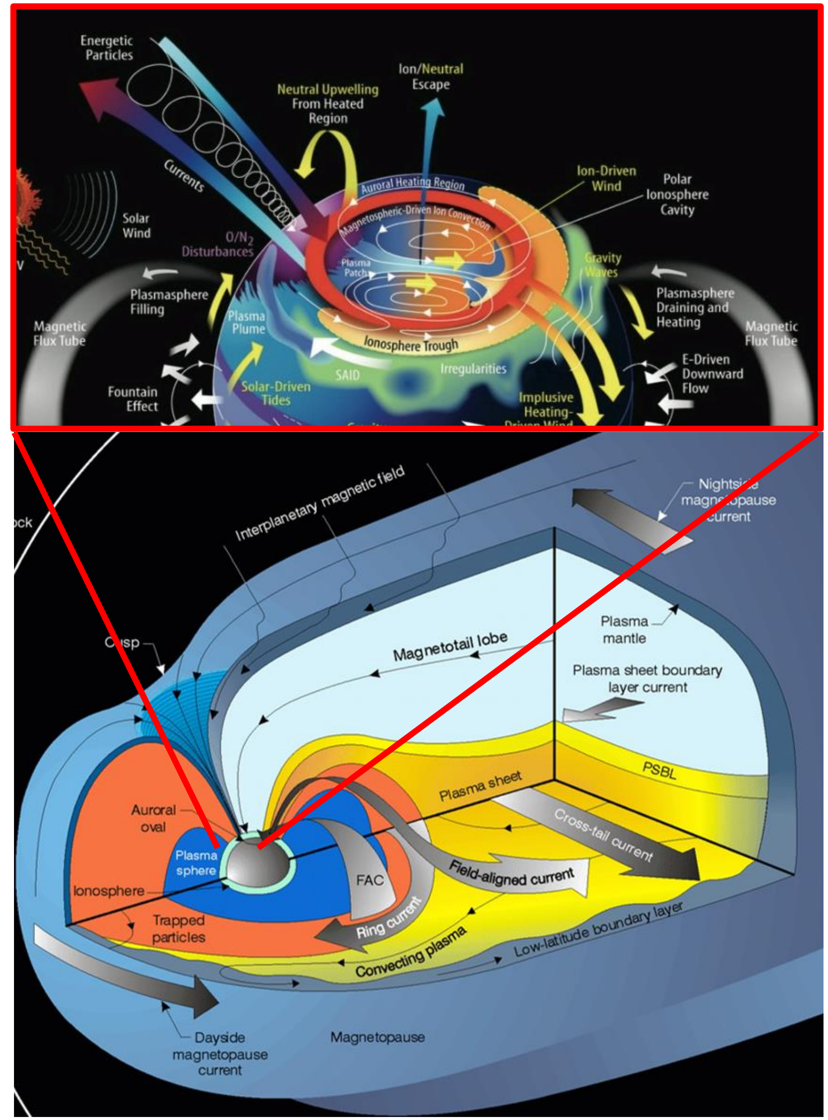
SuperDARN – ionospheric irregularities

Sources: plasma circulation, electron-density gradients, shear flows, temperature gradients.

Instability processes:
Gradient Drift instability (E and F region) – most relevant - strong electric field not aligned with a background plasma density gradient.
(Two-stream instability - E-region, Electrostatic Ion Cyclotron instability - E and F region, Temperature Gradient instability - F region, Kelvin-Helmholtz instability - F region, … ?)

SuperDARN - observations of circumterrestrial space





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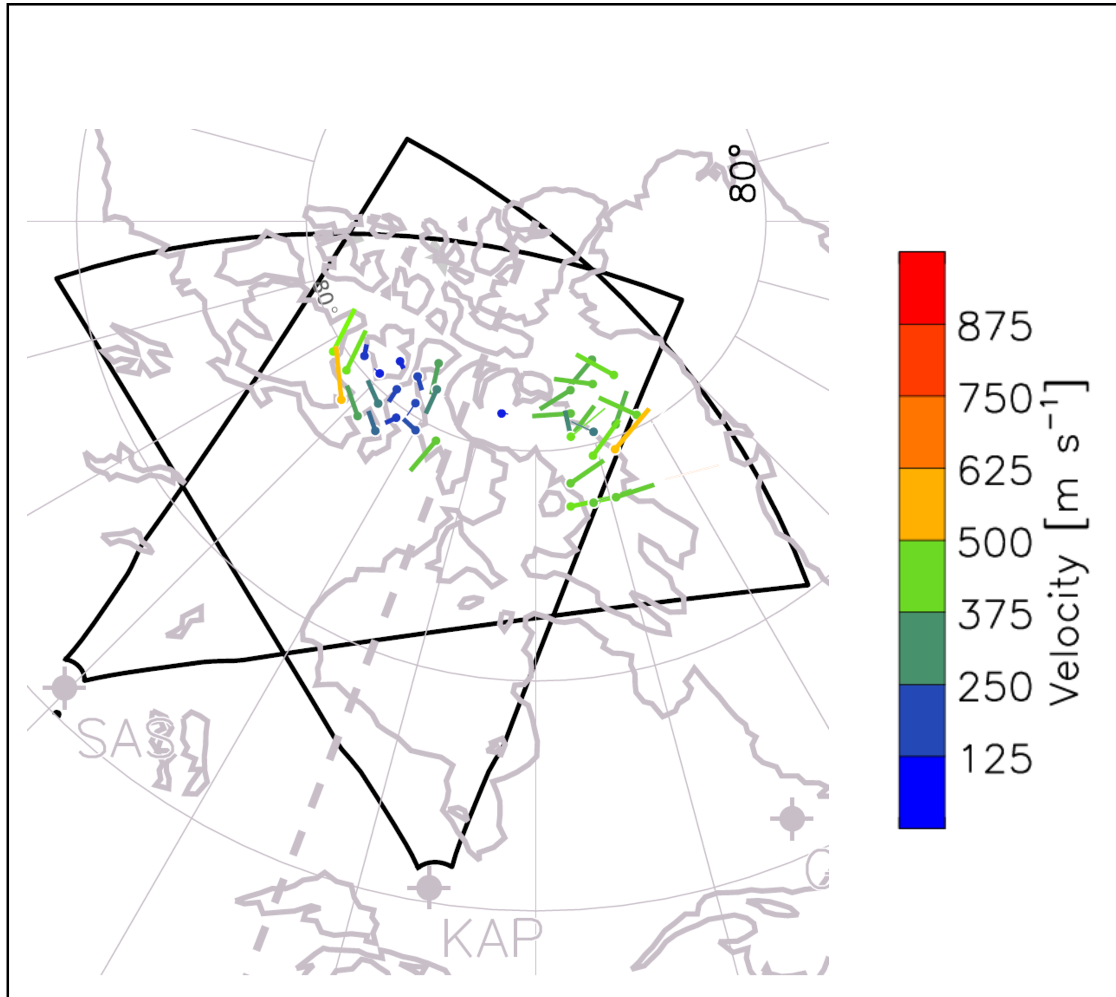
SuperDARN – that's why *Dual*

Usually the radars form pairs:

- their beams intersect roughly at right angles
- the full two dimensional horizontal velocity vector of the ionospheric plasma convection can be calculated from the Doppler speed measured along each beam.



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SuperDARN – coverage

In the 1980s - first coherent-scatter radars to study ionospheric convection at polar latitudes with the Scandinavian Twin Auroral Radar Experiment (STARE)

Radio Science, Volume 13, Number 6, pages 1021–1039, November–December 1978

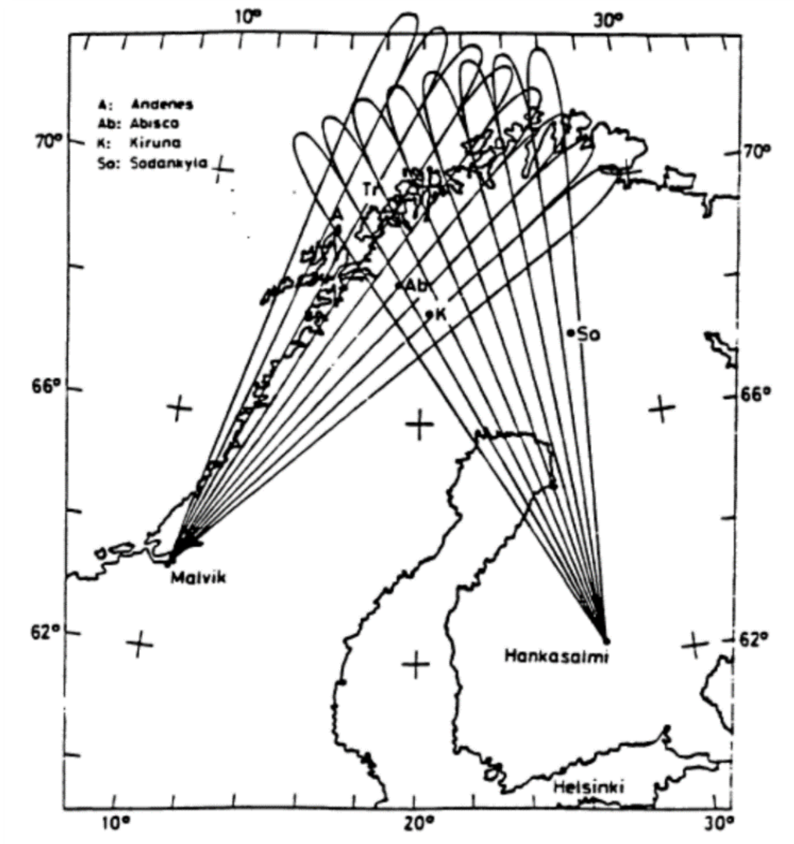
STARE: A new radar auroral backscatter experiment in northern Scandinavia

R. A. Greenwald, W. Weiss, and E. Nielsen

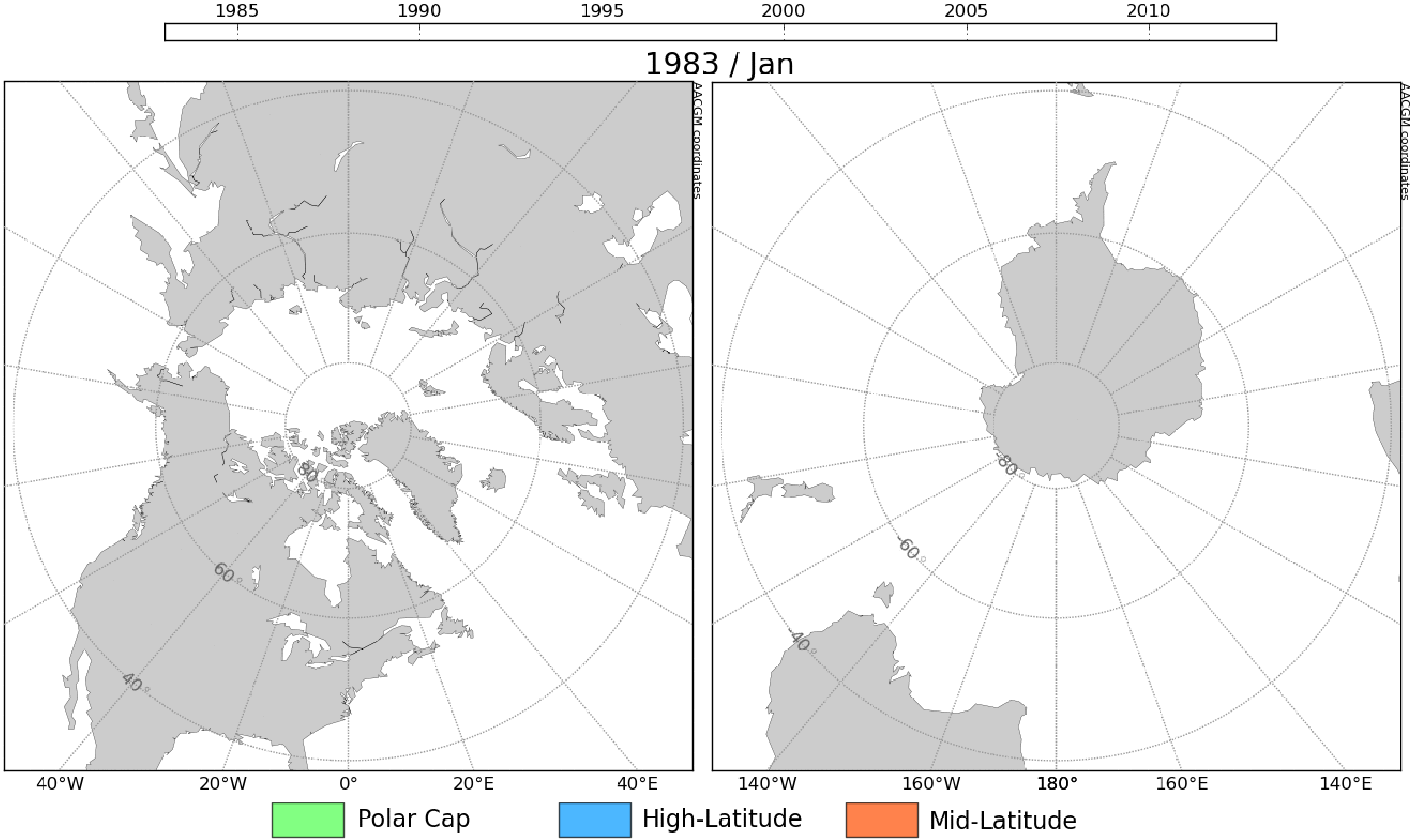
Max-Planck-Institute für Aeronomie, 3411 Katlenburg-Lindau 3, Federal Republic of Germany

N. R. Thomson

Physics and Engineering Laboratory, DSIR, Lower Hutt, New Zealand



SuperDARN – coverage



Thanks to: Space@VT SuperDARN VirginiaTech Invent the Future

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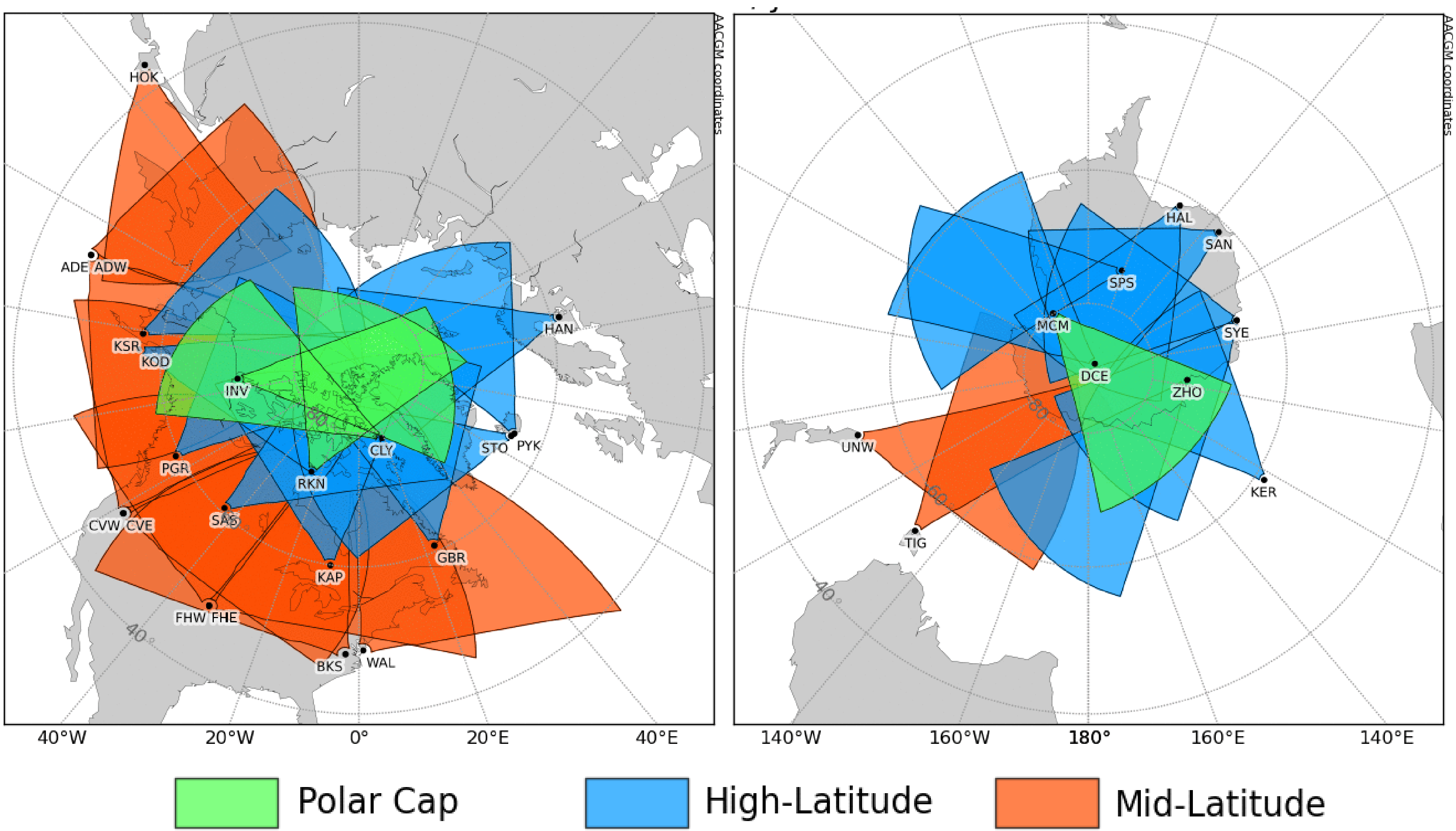
SuperDARN – coverage



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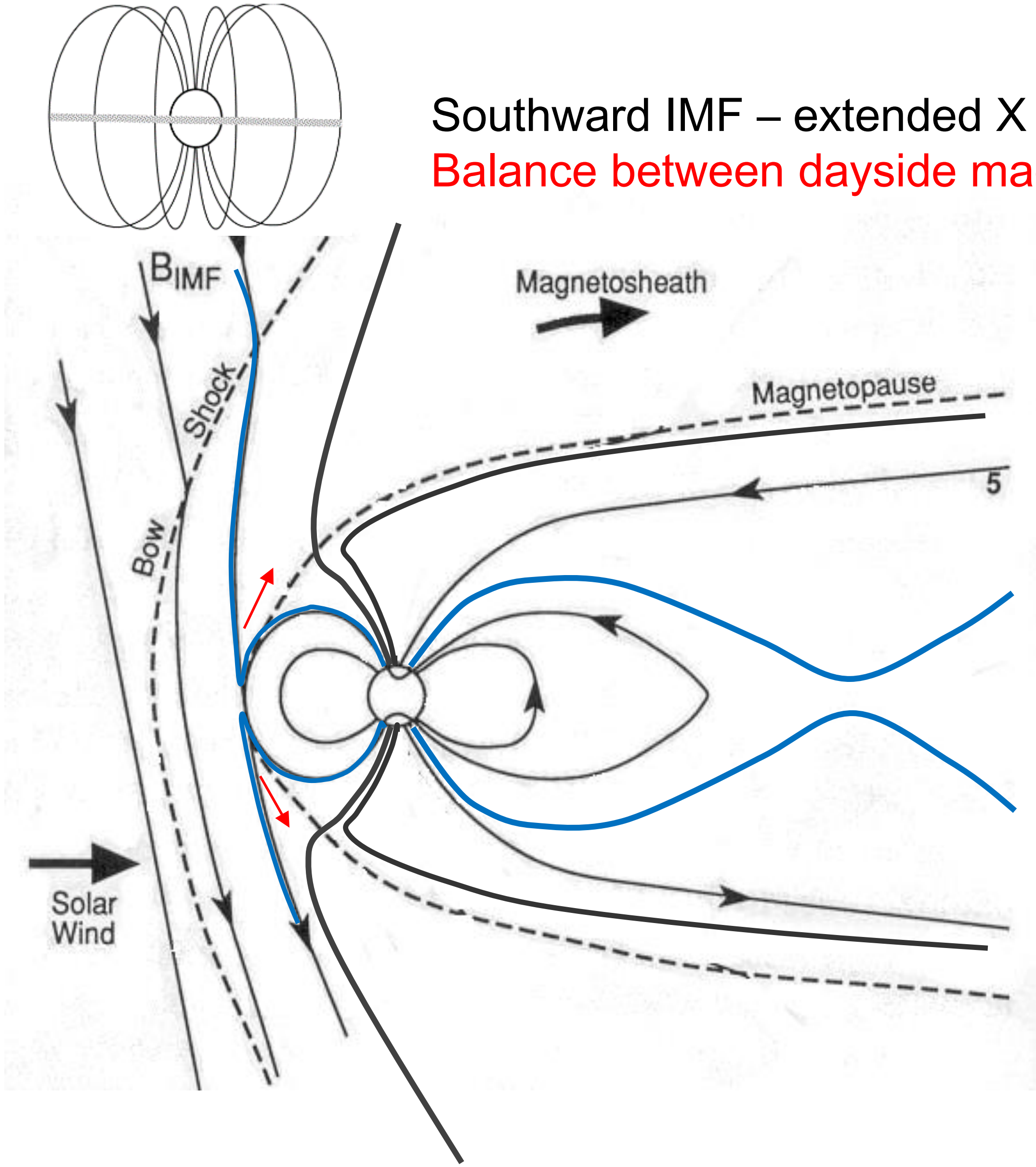
SuperDARN – **global ionospheric convection**

Southward IMF – extended X line – steady reconnection

Balance between dayside magnetopause and tail reconnetion



SuperDARN – **global ionospheric convection**

Southward IMF – extended X line – steady reconnection

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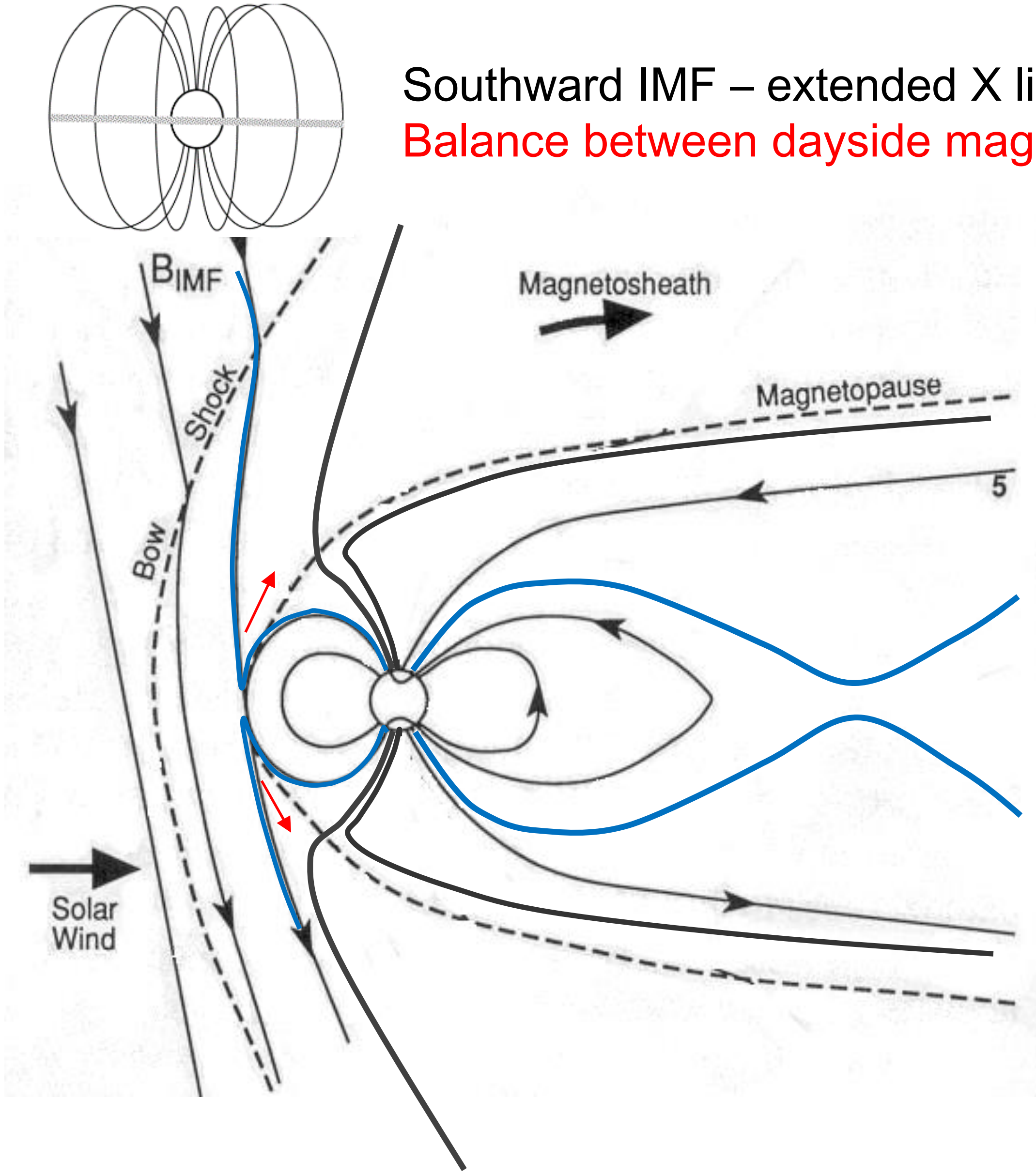
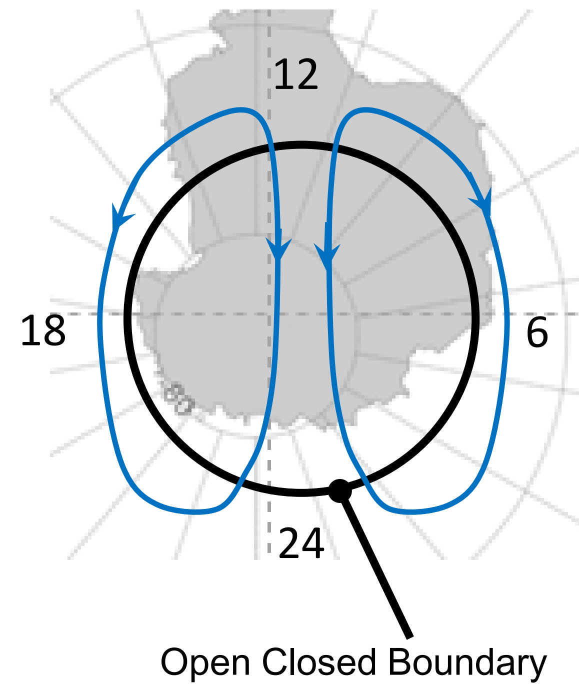
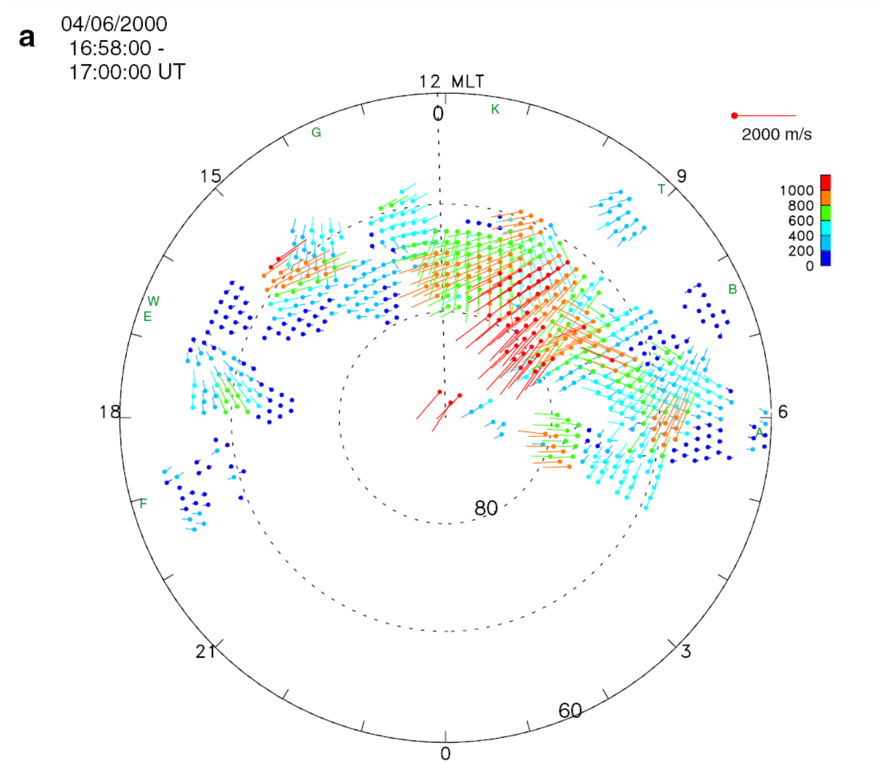
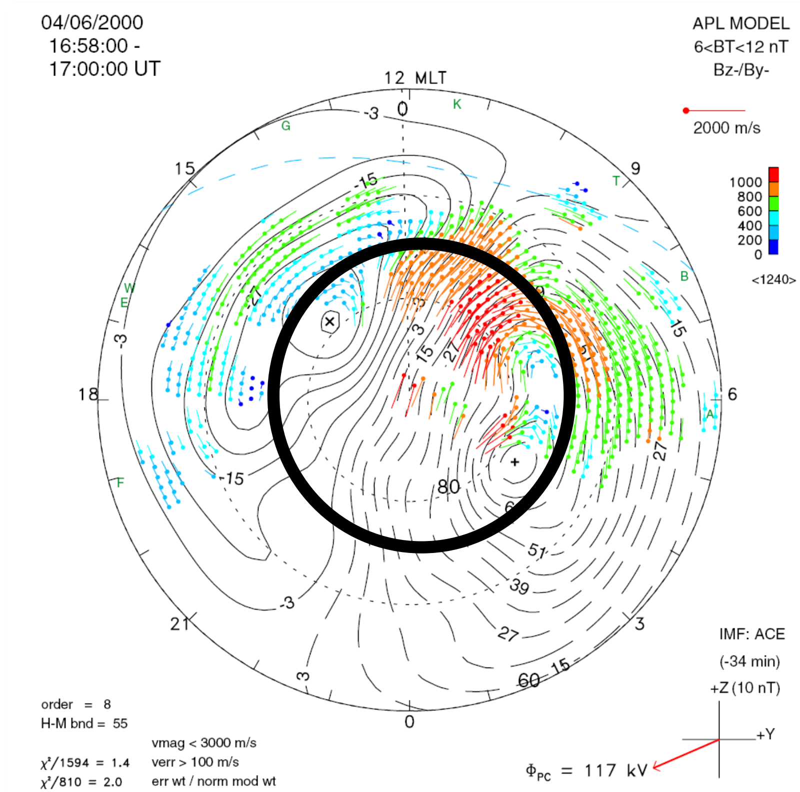




SuperDARN – **global ionospheric convection**



SuperDARN filtered line of sight velocity vectors that have been fitted to an equi-area global grid.

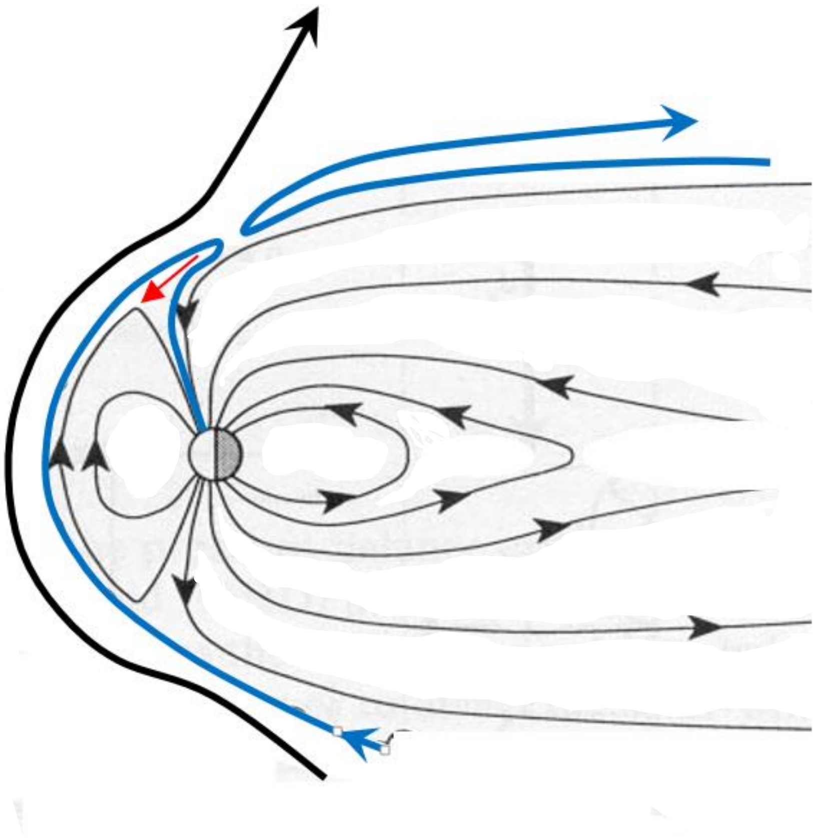


Convection map based on SuperDARN velocity measurements. The measurements are used to determine a solution for the electrostatic potential exspressed as a series expansion in spherical harmonics. A statistical model is used to constraint the solution in region with no data.

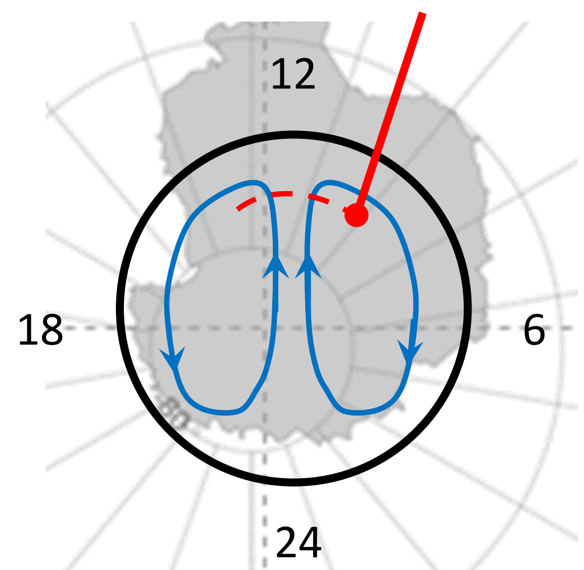
Ruohoniemi and Greenwald, 1996

SuperDARN – **global ionospheric convection**

Northward IMF - Reconnection poleward of the Northern cusp
No tail reconnection



Merging line projection

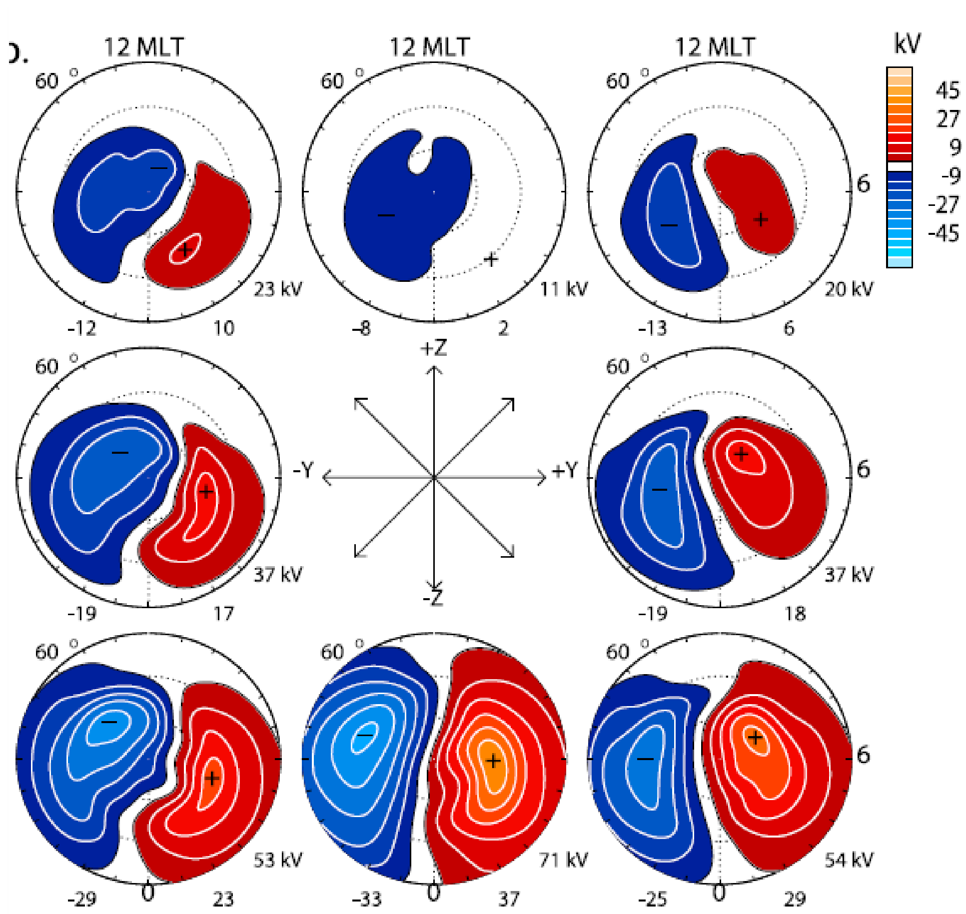


SuperDARN – **global ionospheric convection**

A discrete set of climatological patterns of high-latitude ionospheric convection derived independently for the Northern Hemisphere and Southern Hemisphere and for different

- solar wind
- IMF
- and dipole tilt angle

based on velocity data from nine high-latitude radars in the Northern Hemisphere and the seven radars in the Southern Hemisphere **from January 1998 through December 2005**.

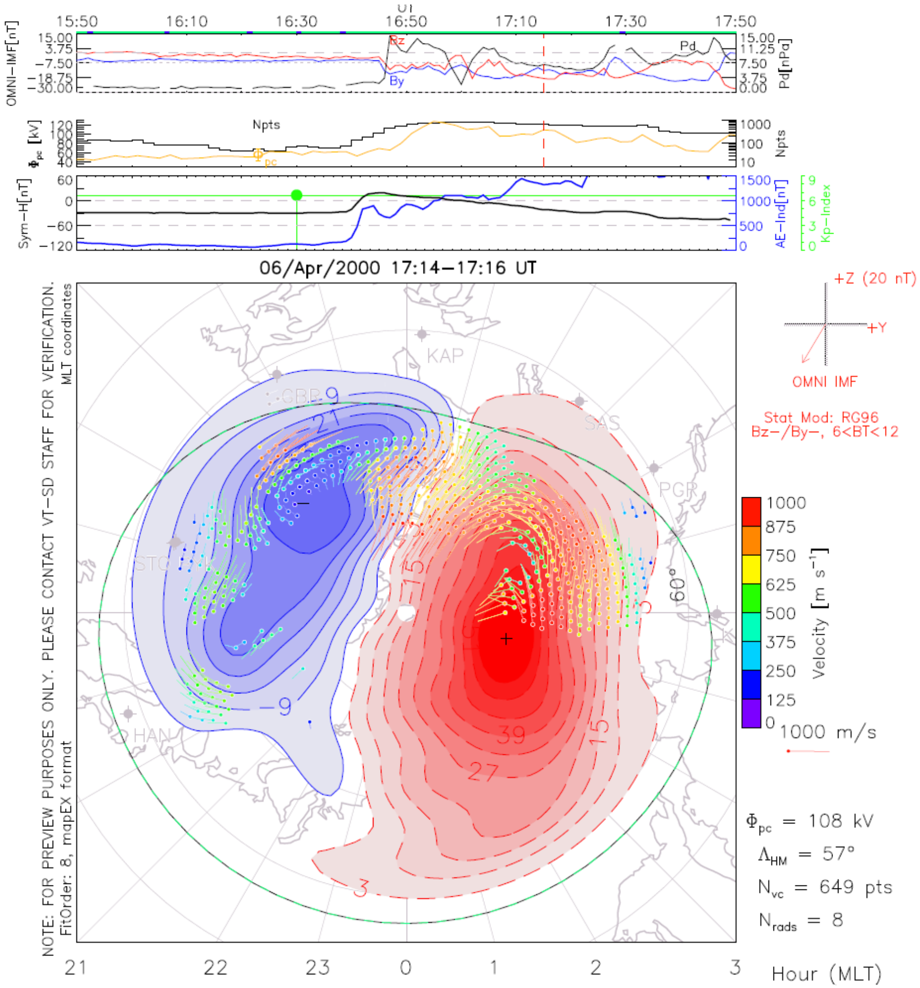


Cousins and Shephard, 2010

SuperDARN – **global ionospheric dynamics**

Following a southward turning the convection intensify rapidly (2 m) and the cross polar cap potential rises to its maximum value in 10 m.

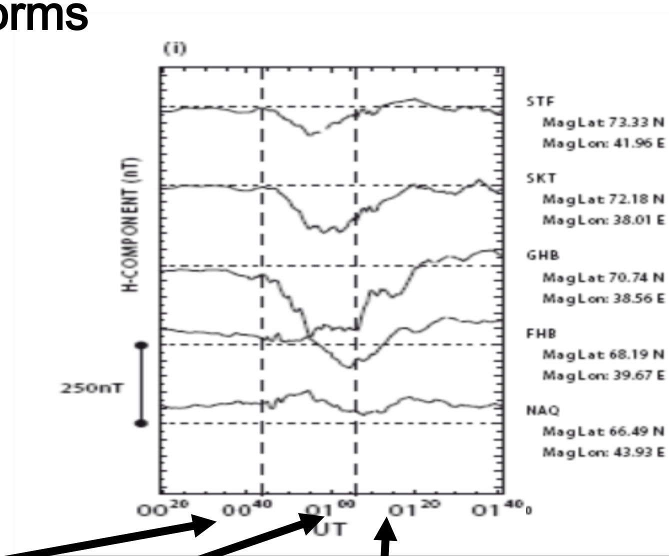
Capability of observing the temporal evolution of the convection reconfiguration in response to variations in the IMF and within the magnetosphere.

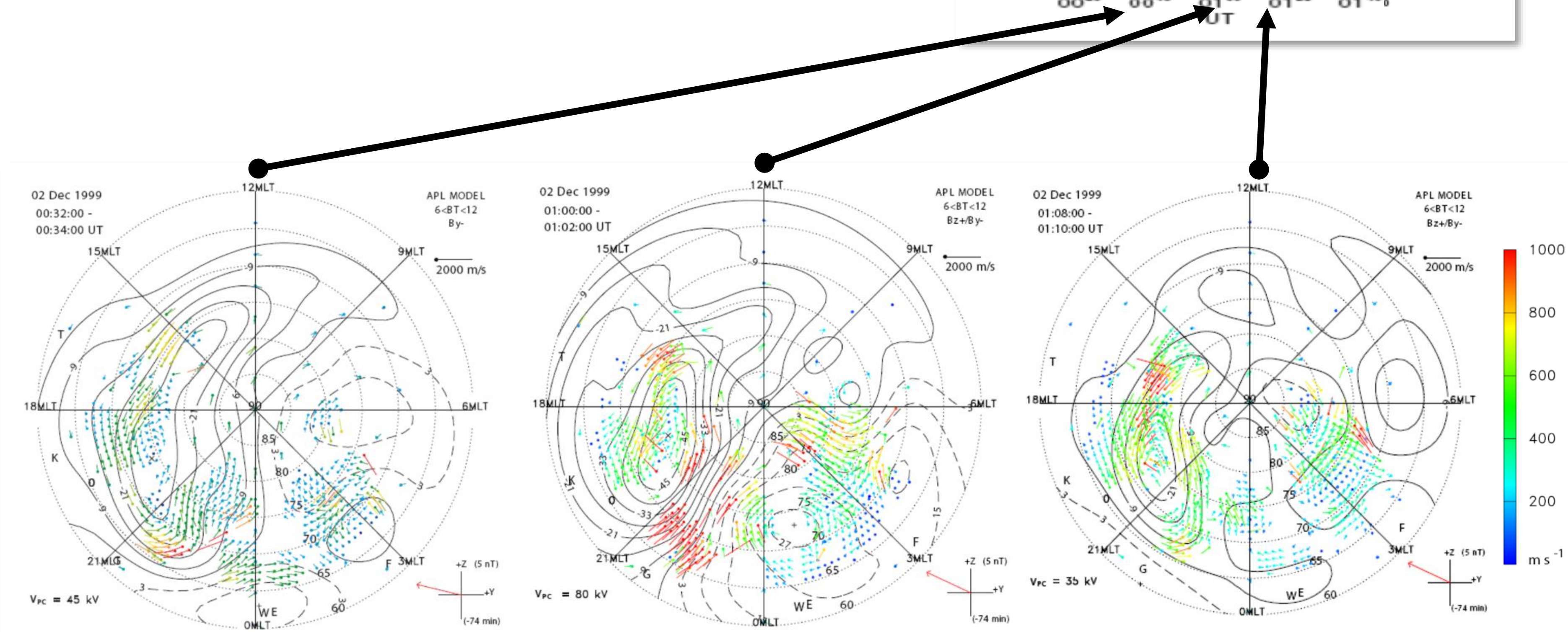


SuperDARN – **enhanced flows associated with substorms**

Substorm occurred during steady northward IMF:

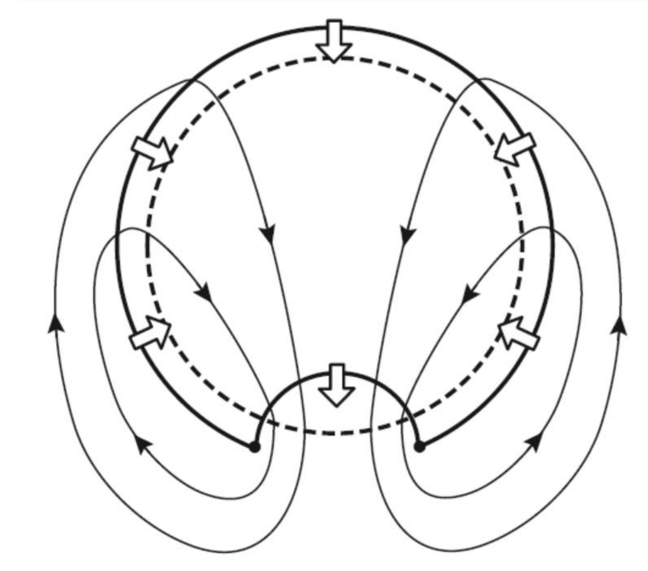
large-scale flow associated with the substorm expansion phase.





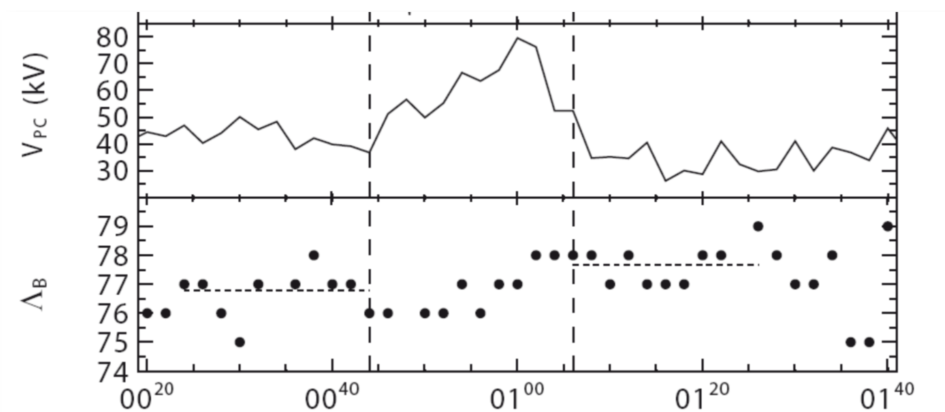
Grocott, 2002

SuperDARN – **enhanced flows associated with substorms**



The flow pattern was of twin-vortex form.

The net closure of open flux represents 15–20% of the open flux present at onset corresponding to an overall contraction of the open-closed field line boundary by 1 degree in latitude.



Total transpolar voltage and the estimate of the latitude of the flow reversal boundary on the dusk meridian, related to the OCB obtained from the minimum in the electrostatic potential

Grocott, 2002

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SuperDARN – **imaging magnetospheric regions with the spectral width**

The Doppler spectral width is a measure of the spatial and temporal structure in the ionospheric electric field on scales comparable to, or less than, the radar measurements.

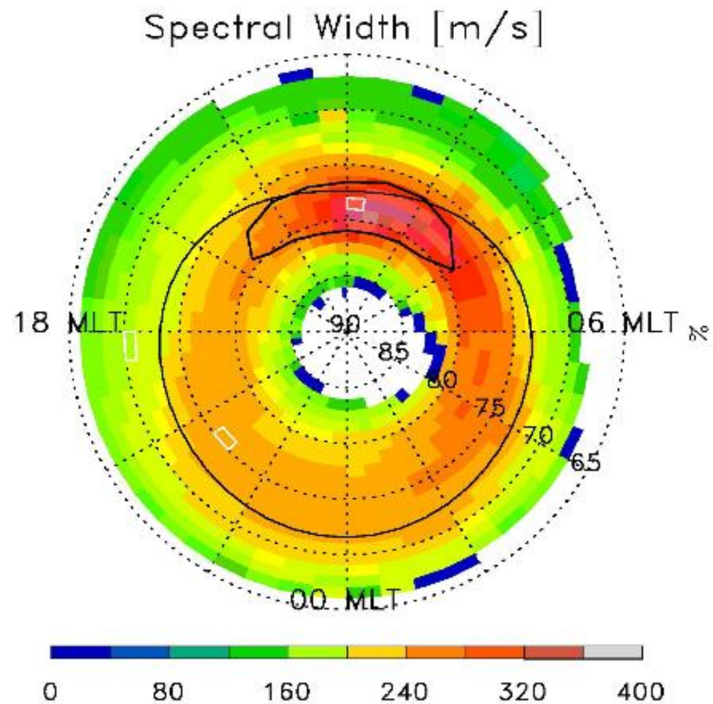
- A region of very high spectral width (350 m/s) is collocated with the ionospheric cusp/cleft region.
- An oval shaped region of high spectral width (250 m/s) near the poleward limit of the Holzworth and Meng auroral oval. This region could be linked to magnetic field lines originating in the outermost regions of the magnetosphere.
- A region of lower spectral width at lower latitude that could be related to closed field lines, associated with regions located deeper in the magnetosphere.
- A region of lower spectral width at very high-latitudes that could be related to magnetic field lines connected with the Interplanetary Magnetic Field (IMF).

Annales Geophysicae (2002) 20: 1769–1781 © European Geosciences Union 2002

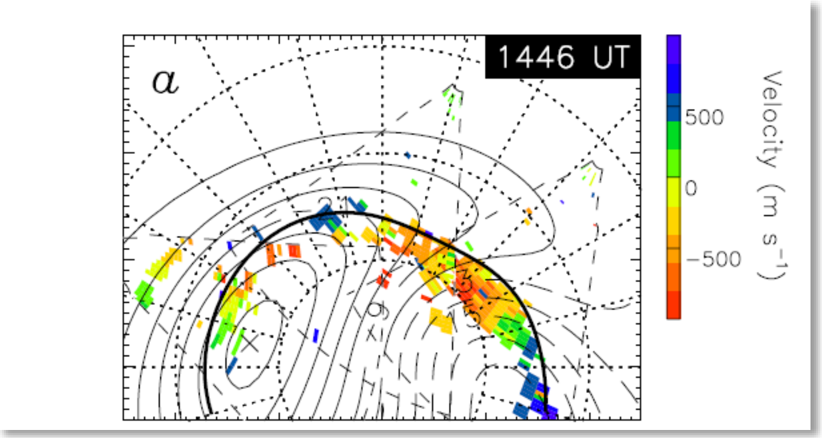
Annales Geophysicae

A Statistical study of the Doppler spectral width of high-latitude ionospheric F-region echoes recorded with SuperDARN coherent HF radars

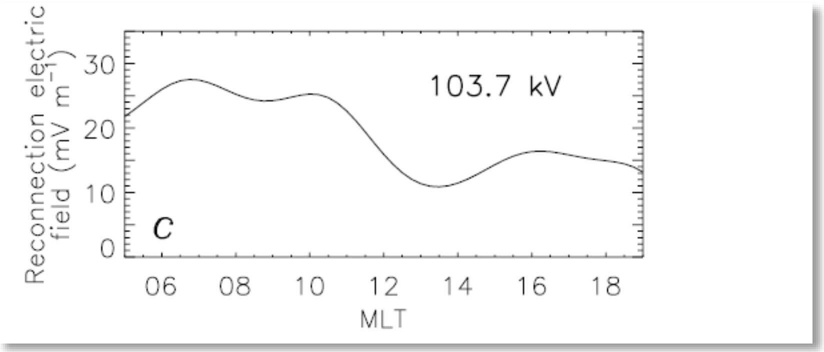
J.-P. Villain[1], R. André[1], M. Pinnock[2], R. A. Greenwald[3], and C. Hanuise[4,*]



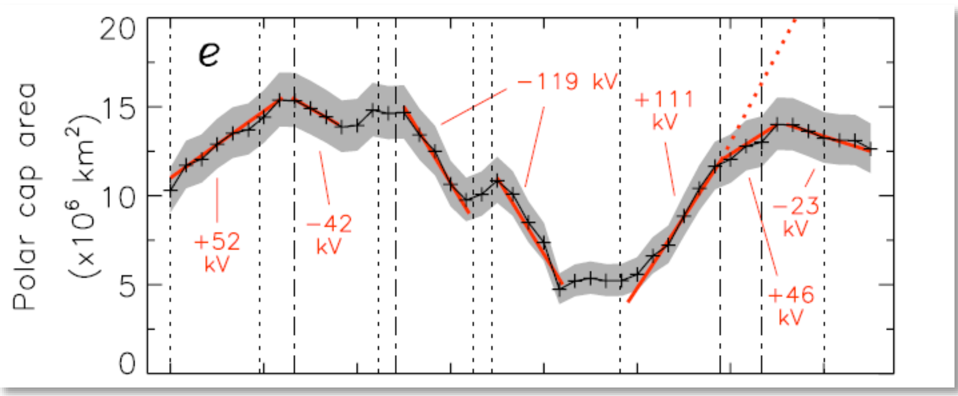
SuperDARN – **OCB identification and reconnection rate estimation**



The OCB (solid line) determined from the equatorward edge of high spectral width backscatter.



The reconnection electric field determined from the plasma drift perpendicular to the OCB. The integral of this along the boundary between 05 and 19 MLT

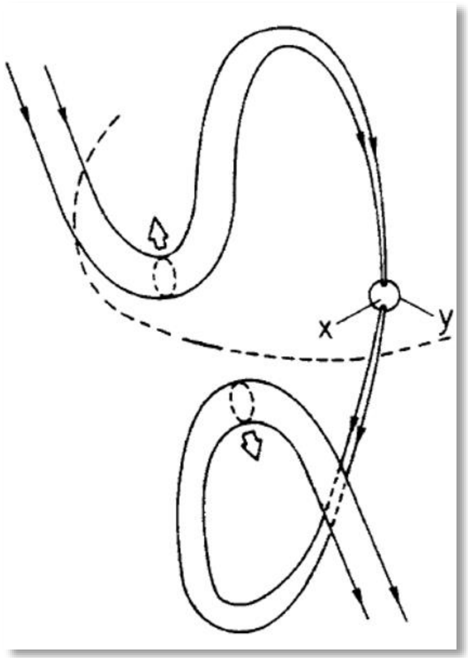


Polar cap area variation deduced from the OCB estimates during substorm

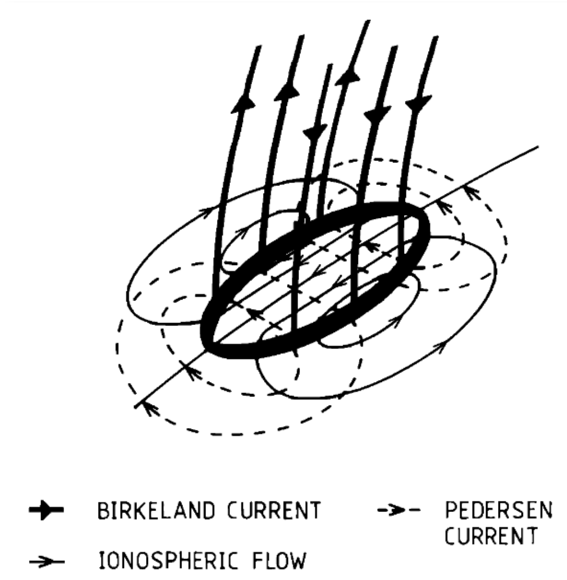
Milan et al. 2003

SuperDARN – **Flux Transient Events**

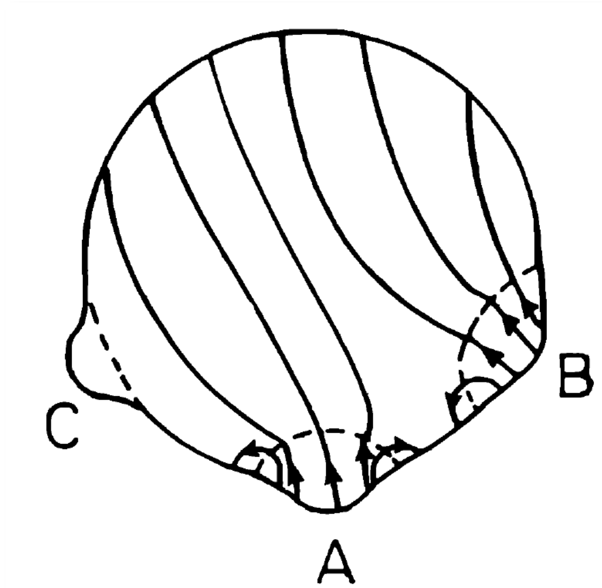
Patchy and transient reconnection



Size 1-2 RE

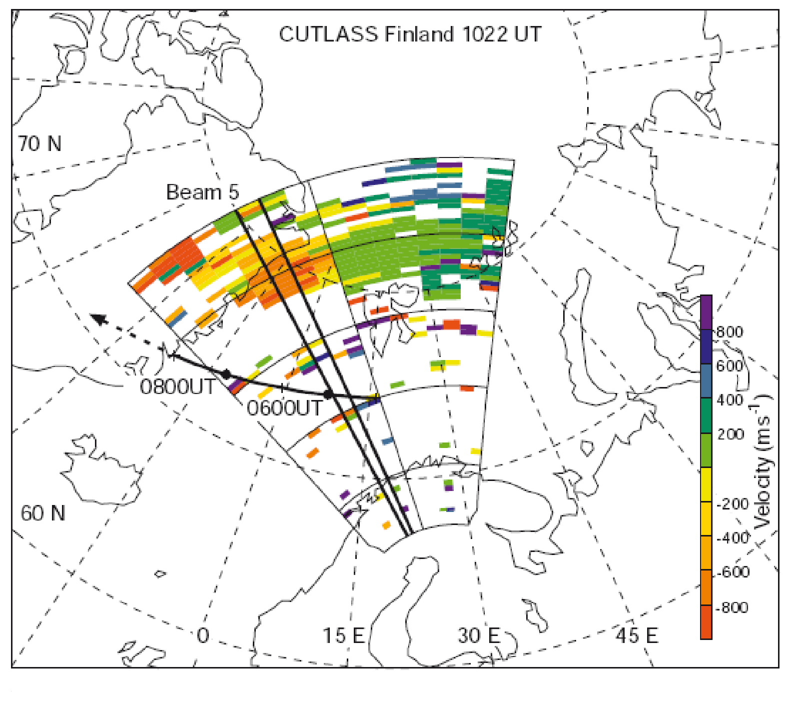


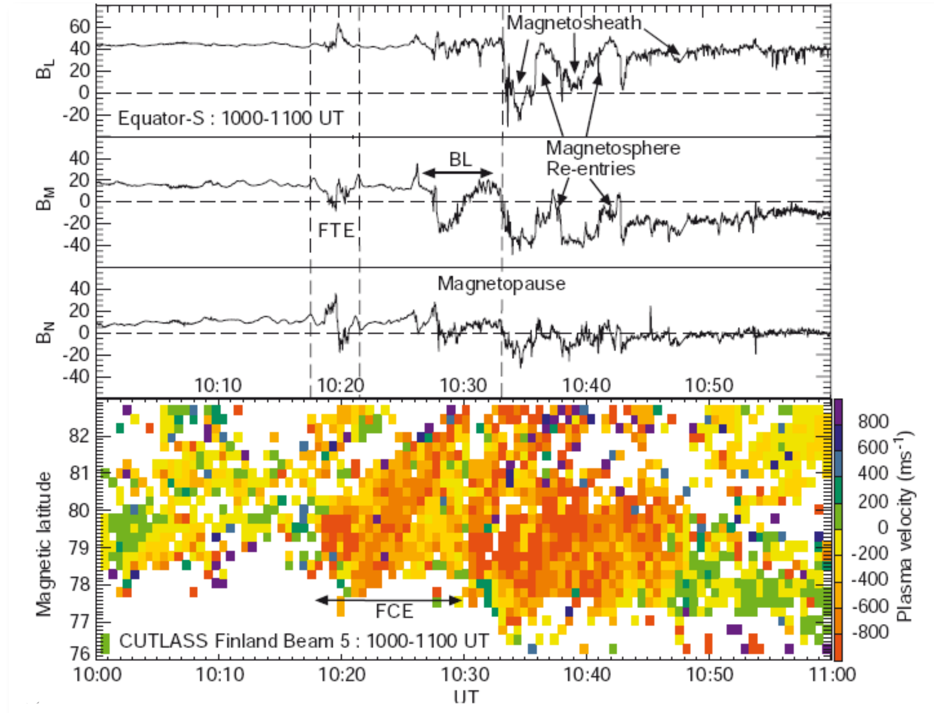
Southwood (1987) model



Mesoscale signature on ionospheric convection

SuperDARN – **Flux Transient Events**



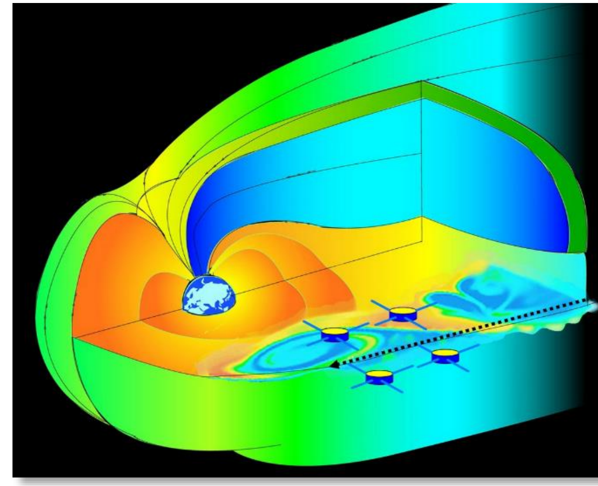


"Flow channels" on newly-opened cusp field lines

The equatorward border of the region of backscatter moves equatorward consistent with an overall expansion of the polar cap.

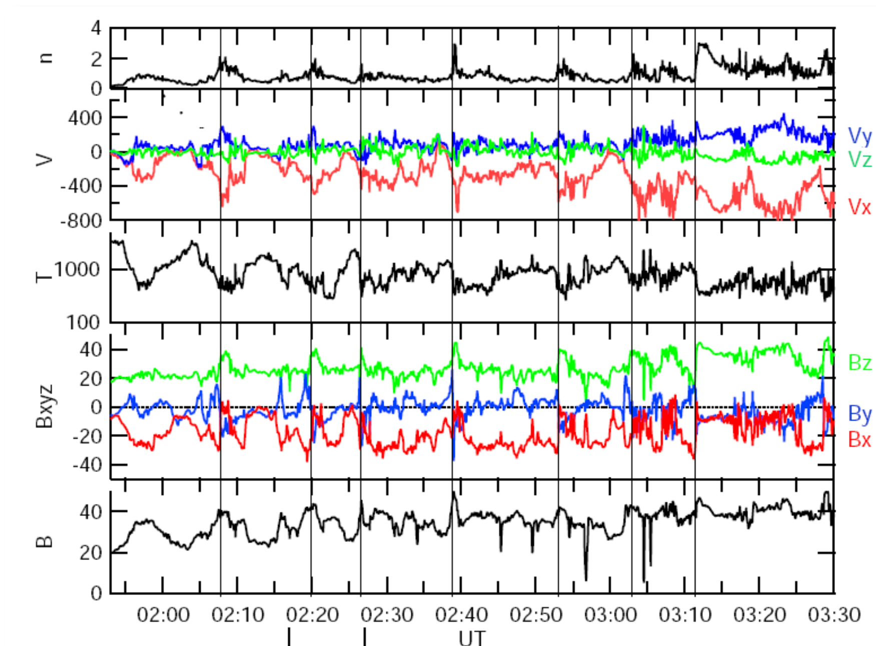
Neudegg et al., 1999

SuperDARN – **K-H at the magnetopause**



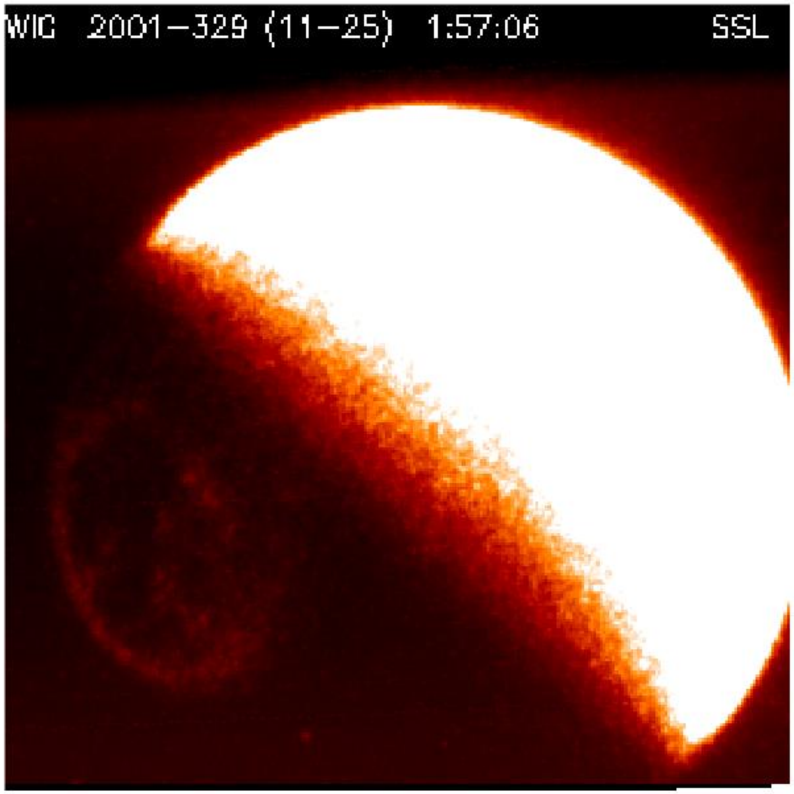
When a large a large velocity shear exists across the MP, the condition for onset of KHI are favorable and large scale vortices develop at the flank of the magnetopause

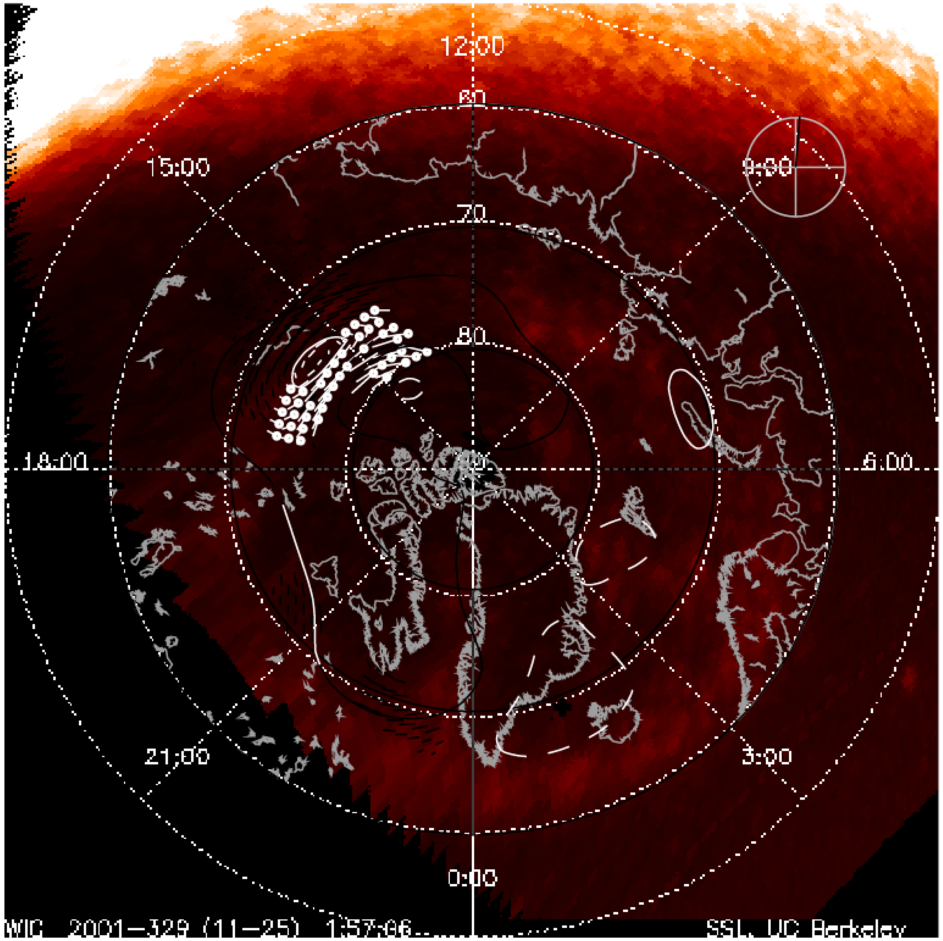
During a long lasting period of northward interplanetary magnetic field and high solar wind speed (above 700 km/s), Cluster spacecraft constellation traversed the dusk magnetopause and went across a number of very large rolled-up Kelvin-Helmholtz (KH) vortices.



Bavassano Cattaneo, 2010

SuperDARN – **K-H at the magnetopause**

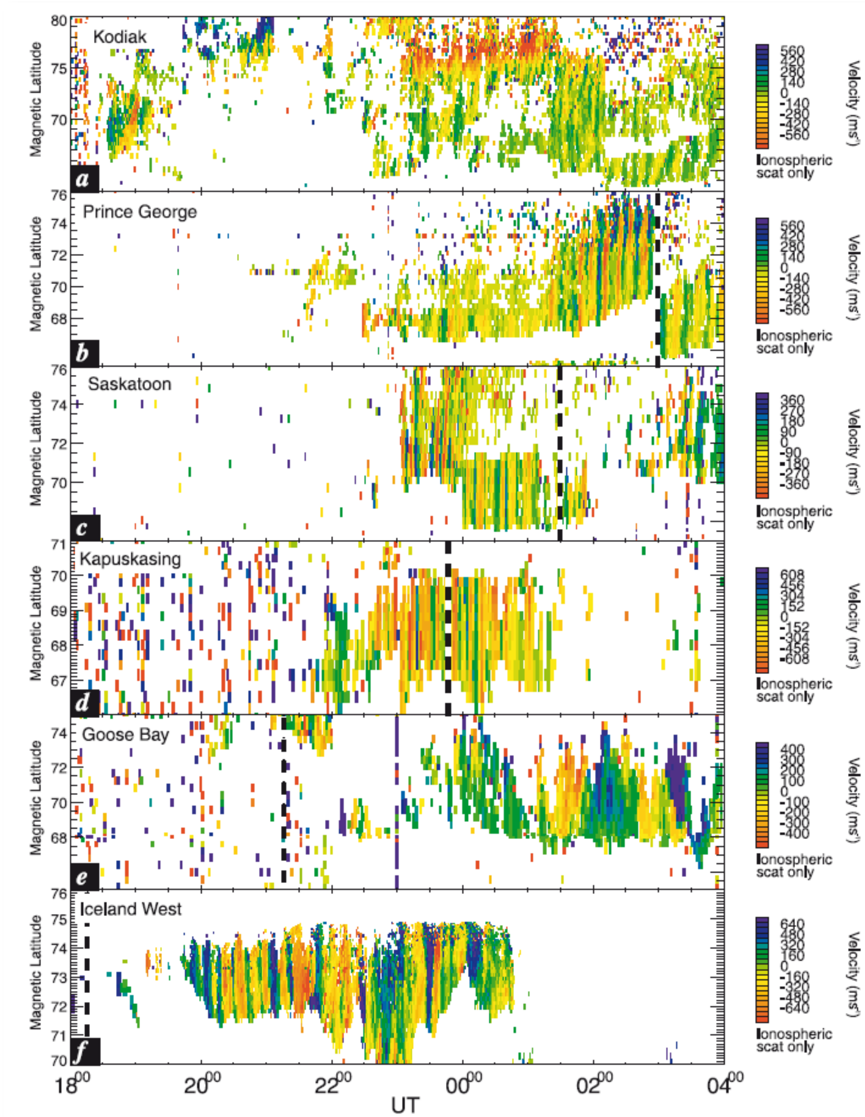




SuperDARN – **K-H at the magnetopause**

Large-amplitude nearly monochromatic pulsations were observed ubiquitously in the magnetosphere and ionosphere.

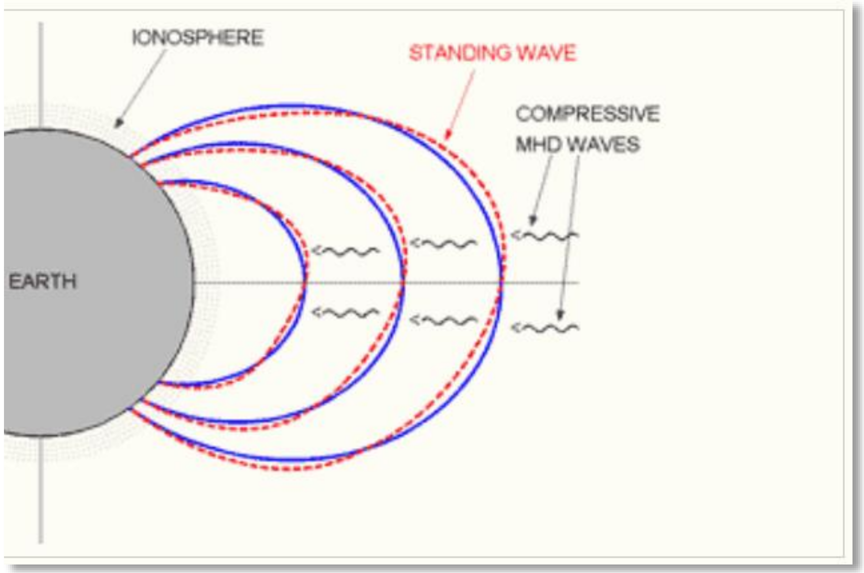
Since the SuperDARN HF radars appear to be poleward of the region of the excited FLR and map to L shells close to the magnetopause, the ionospheric flows must be related to the K-H mechanism rather than the excited field line resonance observed in the magnetometer stations.



Rae et al., 2005

SuperDARN – **ULF waves**

Different processes taking place in the magnetosphere results in two types of MHD waves:
The magnetosonic wave - propagating in any direction and generating compression and rarefaction both of the magnetic field and plasma;
Alfvén waves - propagating along the direction of the ambient magnetic field and producing magnetic perturbations transversal to the field lines.

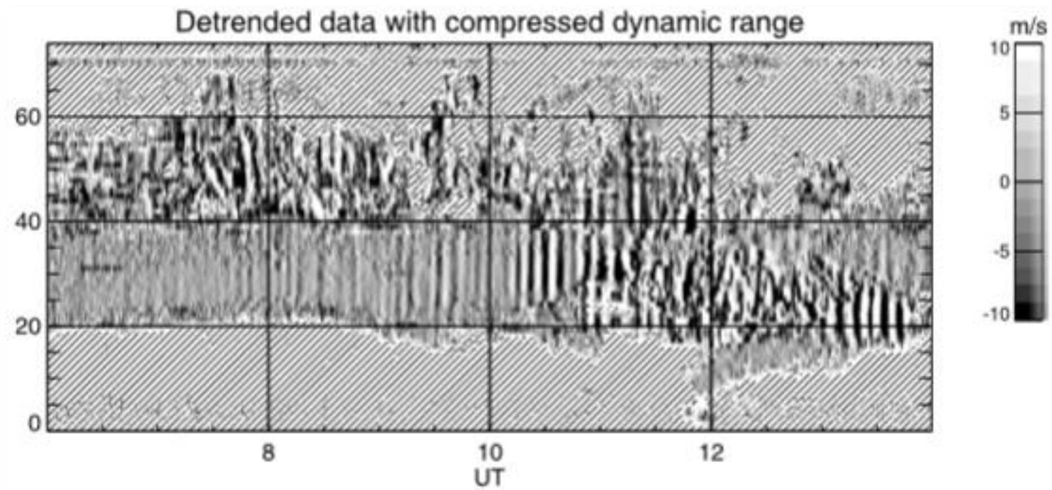


Origin of ULF can be in the solar wind or internal

SuperDARN – **ULF waves**

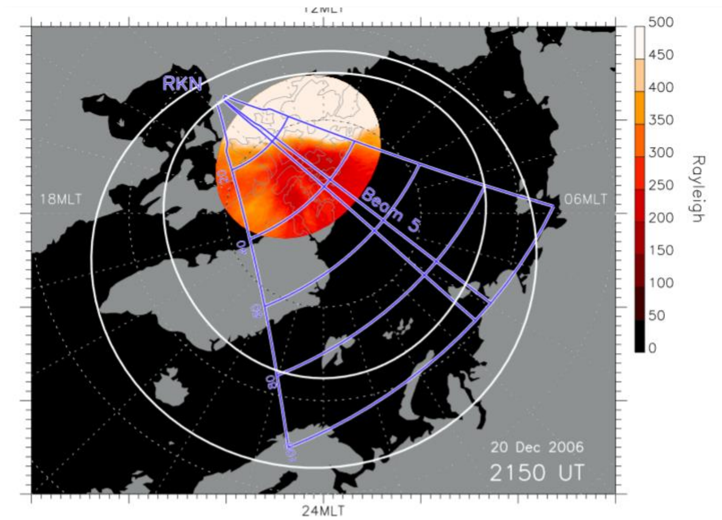
Periodic oscillations in the Doppler velocity arise due to the drift velocity generated in the ionosphere by the ULF wave electric field and background geomagnetic field.

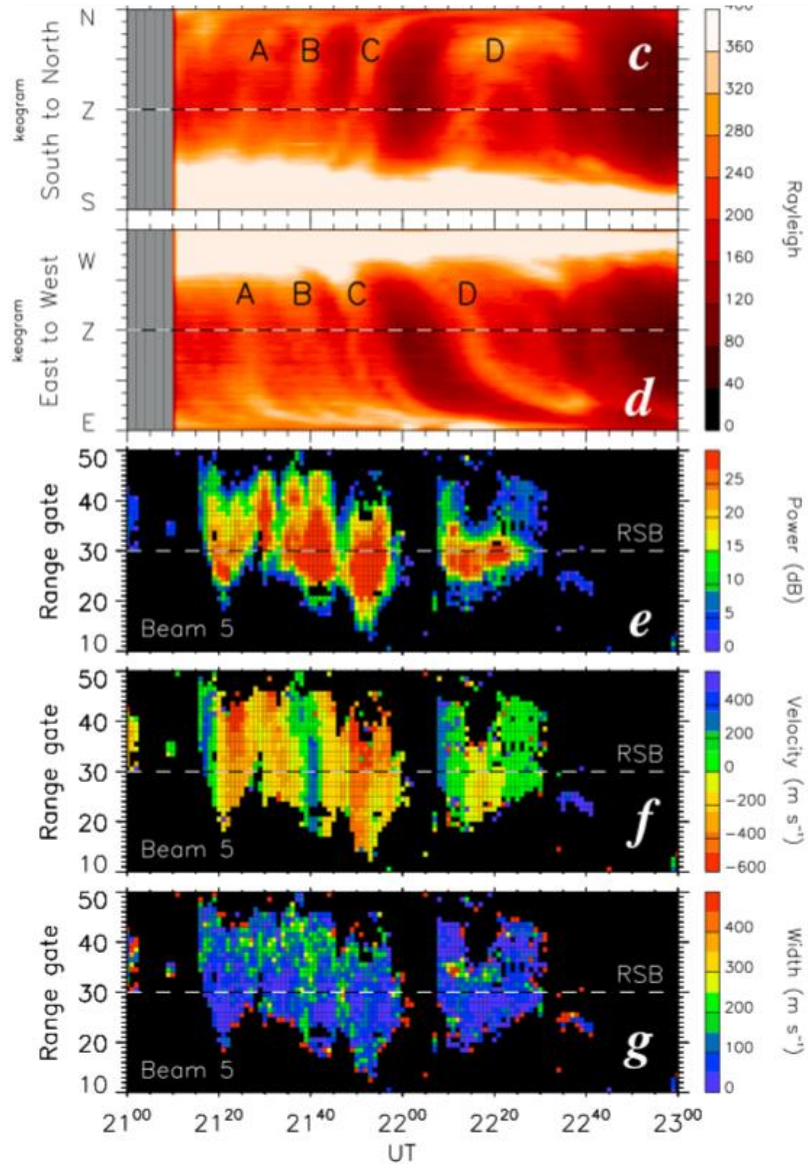
In ionospheric backscatter, these oscillations arise mostly from the horizontal component of V and have amplitudes up to about 100 m/s.



Ponomarenko et al. (2002)

SuperDARN– **polar cap patches**





Radar echoes are caused scatter from field-aligned irregularities associated with polar patches.

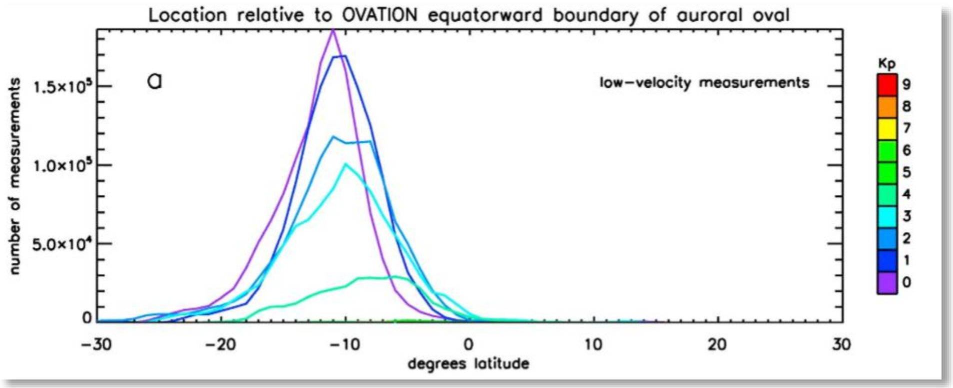
Investigation of the instabilities producing the irregolarities and dynamics of patches

Hosakawa et al. 2009

SuperDARN– mid latitude radars

Mid latitude radars - new areas of research. SuperDARN in this latitude region commonly make measurements within the region of the ionosphere that is conjugate to the inner magnetosphere

- Subauroral Polarization Streams during geomagnetic storms
- Penetration electric fields during storms and non-storm periods
- Structuring and transport of sub auroral plasma (plasmaspheric plumes)
- Subauroral plasma irregularities (plasmasphere instabilities)
- ULF waves and pulsations



The mid latitude ionosphere is quite active as far as irregularities presence, the associated scatter has low Doppler velocities and spectral widths and is distinctly sub-auroral - on field lines that map into the plasmasphere.

Ribeiro et al. 2013

SuperDARN– summary of topics and conclusions

Structure and dynamics of global ionospheric convection.

Mesoscale signatures of magnetosphere-ionosphere coupling.

Ionospheric flow bursts associated with magnetopause reconnection (FTEs).

Convection associated with auroral substorms.

Electromagnetic waves:MHD, ULF, Magnetic Field Line Resonances.

Ionospheric irregularities and highlatitude plasma structures (patches).

New radars coming and room for further exploitation of SuperDARN measurements

Visit SuperDARN site @ Virginia Tech **http://vt.superdarn.org**!