

# SuperDARN Workshop 2016

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## Abstracts



## **PI's report**

M. Lester and SuperDARN PIs

## **Scheduling Working Group report**

G. Chisham

*British Antarctic Survey, Cambridge, UK*

## **Spacecraft Working Group report**

K. T. Sterne (1), R. C. Fear (2), \*J. M. Ruohoniemi (1), T. Hori (3)

*(1) Virginia Tech, Virginia, USA,  
(2) University of Southampton, England, UK,  
(3) Nagoya University, Japan*

Reporting on the spacecraft happenings and updates from the last Workshop.

## **Data analysis Working Group report**

P. Ponomarenko

*University of Saskatchewan, Saskatoon, SK, Canada*

Report on the WG activity since the last SuperDARN workshop.

## **Data distribution Working Group report**

K. Krieger

*University of Saskatchewan, Saskatoon, SK, Canada*



## The Svalbard SuperDARN radar - first light

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The Svalbard SuperDARN radar is located at 78 degrees N and co-located with other space research infrastructure. After four years of planning, red-tape and construction work, the construction of the radar was finalized at the end of October 2015, and first light was 3. November. The radar is currently in a commissioning phase and has been running intermittently for the last 6 months. In addition to being stored locally, data from the radar is also being transferred to data servers at BAS. In this talk we present an update on the state of the radar, and have a look at the initial data taken during the commissioning phase.

## Construction progress of the AgileDARN in China

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We have been constructing the AgileDARN from the beginning of 2015 with the support of the National High-tech Research and Development Program of China. The radar is located in Jiamusi, a city of extreme northeast China. The coordinate of the radar is 46.8°N geographic latitude, 130.47°E geographic longitude, and its boresight direction is 44° North to East. As a digital generation, phasing network and digital system will be implemented in FPGA. The high digitalization will provide greater flexibility, particularly in antenna beam steering. In the last year, progress has been made on and off site. The antenna array has been built up by the end of 2015. The hardware of the radar digital system has been in the position. The software of the digital system and T/R units are being developed. The radar is expected to be operational by the middle of 2017.

## Calibrating SuperDARN interferometers using meteor backscatter

G. Chisham

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Accurate geolocation of ionospheric backscatter measured by the SuperDARN radars is crucial for combining measurements from multiple radars or when comparing data with that from other instrumentation. Interferometers are now playing an increasing role in the geolocation of SuperDARN backscatter although all the radars are characterised by different calibration factors which makes the geo-positioning of measurements challenging and hence the accuracy variable. We present a method for determining the calibration factor for each radar using low-altitude measurements of meteor scatter from the upper mesosphere and lower thermosphere. The calibration factors vary between different radars and also show clear variations with changing radar operating frequency. More surprisingly the calibration factors show a seasonal variation, and potentially longer-term trends which may be related to longer term variations in activity such as the solar cycle.



## Calibrating SuperDARN interferometer arrays

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Elevation angles of returned backscatter are calculated at the SuperDARN high frequency radars using interferometric techniques. These elevation angles allow the altitude of the reflection point to be estimated, an essential piece of information for many ionospheric studies. One of the most difficult parameters to measure is the time delay caused by the difference in the electrical path length between the main array and the interferometer (tdiff). Measurement difficulties arise from the design and location of the radars, and are complicated by the possibility of sudden external changes, slow temporal drift, and a dependence on transmission frequency. However, it is possible to estimate tdiff using existing radar observations. This paper presents a method for estimating tdiff using ionospheric backscatter with a known location.

## Evaluating transverse ionospheric drift velocity from spatial correlation analysis of oblique, high-frequency groundscatter

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A method of deriving transverse ionospheric drift velocity from oblique, high-frequency (HF) ground scatter is presented. Specifically, an algorithm for estimating the transverse ionospheric drift velocity from the two-point, two-time mutual coherence function (MCF) of a ground clutter cell measured by a HF radar with a linear aperture is considered. Starting from the Huygens-Fresnel principle, a series of reasonable approximations can be made to derive a simple Fourier transform relationship between the MCF observed in the radar aperture and the auto-correlation of the signal scattered from a ground clutter cell. The MCF derived under these approximations has elliptical amplitude contours in the space-time plane whose principle axes lengths and orientation may be related to the azimuth intensity pattern of the radar, the fading time of the signal scattered from the ground clutter cell, and a transverse ionospheric drift velocity. The theoretical MCF derived is shown to accurately replicate the features of ground clutter MCF's observed by the Kodiak radar. Measurements of transverse ionospheric drifts made by applying the technique developed here to ground clutter observed by the Kodiak radar is presented.



## Validation of SuperDARN methods for geolocation and refractive index determination using ionospheric ray tracing

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In this paper, we present the results of a comparison between ray tracing analyses of HF propagation in the ionosphere at different local times and predictions of the Standard, Chisham, and 2-Parameter Methods for determining the ground range to ionospheric scattering volumes. The analyses are carried out at three local times:  $\sim 21$ ,  $\sim 07$ ,  $\sim 13$  LT. From each of the ray tracing analyses, we determine all locations  $\{\alpha, L\}$  where the propagation vector of the ray is nearly orthogonal to the geomagnetic field and related critical information  $\{LG, nR\}$ , where  $\alpha$  is the initial elevation angle of the ray,  $L$  is the group range to the scattering volume,  $LG$  is the ground range to the scattering volume, and  $nR$  is the refractive index of the scattering volume. The values  $\{\alpha, L\}$  are measurable quantities that can be provided by SuperDARN radars with interferometric capability. In this simulation, these data pairs are input to the Standard, Chisham and 2-Parameter Methods. For this analysis, the Standard and Chisham Methods have been enhanced in the following ways. First, they make their predictions of  $LG$  from  $\{h(L), L\}$ , where  $h(L)$  are different virtual height models that are used by the two methods. We retain this part of their analysis, but we also calculate  $\alpha'$ , which is the value of  $\alpha$  that is self-consistent with  $h(L)$  from their virtual height models. We then determine the vertex of the obtuse triangle that is in the ionosphere to get the angle of incidence of the equivalent straight line and apply Snell's Law to predict the refractive index in the ionospheric scattering volume. We should note that a related usage of Snell's Law has been used for nearly 90 years to get true height ionospheric electron density profiles from oblique bistatic sounding systems. The remainder of this paper deals with comparisons of  $\{\alpha, L\}$  from ray tracing and  $\{\alpha', L\}$  from the Standard and Chisham Methods. The 2-Parameter Method uses the  $\{\alpha, L\}$  values from ray tracing. It should be apparent that if  $\alpha \neq \alpha'$ , then all of the angles of the triangle will be incorrect. Overall, there is poor agreement between the predictions  $\{LG, nR\}$  from ray tracing and the predictions  $\{LG, nR\}$  from the Standard and Chisham Methods. These are caused mainly by the constraints of the virtual height models that are used. Most importantly, these models provide static predictions that do not respond to temporal variations in the ionization of the ionosphere.

### Magnetic Local Time and AACGM-v2

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Many plasma processes in the thermosphere, ionosphere and magnetosphere appear to be well-organized by magnetic latitude and magnetic local time (MLT). There are numerous coordinate systems used to specify magnetic latitude, including magnetic dipole coordinates using a fixed dipole or more complicated ones based on a magnetic field model such as IGRF. These more complicated systems, such as AACGM, AACGM-v2, and Apex coordinates, involve tracing magnetic field lines in order to determine a mapping between magnetic and geographic positions, however, functional forms are provided in order to speed calculations. The coefficients of these fitted functions are often used interchangeably with the definition of the coordinate system. Recently it was shown that the coefficients for the AACGM coordinate system were inconsistent and inaccurate and a new set of coefficients was developed; AACGM-v2. This presentation examines several issues related to MLT and AACGM-v2 and suggests a resolution.



## FITACF 3

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The original software package for analysing SuperDARN data, FITACF 1, has been developed in the early 1990s. Its core routines represent a semi-empiric implementation of the weighted linear Least Squares algorithm to fit model functions to the measured auto-correlation functions (ACF) of the radar echoes. Over the last two decades, these routines remained essentially unchanged producing satisfactory estimates of the main information parameters. However, a high degree of coupling between different parts of the software made it hard to modify the code and to trace down errors, and over the years a number of unresolved issues accumulated. While the partially revised FITACF 2 package was released in 2007 and addressed some of these issues, with time passing a more fundamental revision looked inevitable. Unrealistic velocity error estimates produced by the latest version of FITACF 2 turned to be the “last drop” triggering such a revision, which was duly performed by the Saskatoon group in 2012-13. Our analysis revealed that the current implementation of the Least Squares algorithm is non-optimal in estimating phase and power variance, which are used as weighting coefficients in data fitting. Furthermore, a simplistic treatment of the cross-range interference unnecessarily reduces amount of the otherwise valid data. The required changes have been discussed and approved by the Data Analysis working group, and the whole package has been re-written “from scratch” by the end of 2015 at the University of Saskatchewan. The new package, FITACF 3, addresses the issues with optimisation of the data analysis routines. Furthermore, the code is characterised by a high degree of modularity and utilises a self-contained data structure, which significantly simplifies its testing and modification compared to the previous versions. The new software has successfully passed extensive testing using simulated ACFs and showed its reliability in estimating major signal parameters and their errors over a broad range of the input values. Limited testing of FITACF 3 against real data revealed significant increase in the number of utilised data points, but more extensive checking by other groups is required before incorporating the new package into the officially distributed SuperDARN software.

## Comparison of 7 and 8 pulse transmit sequences

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The pulse sequence for SuperDARN radars used to consist of a 7 pulse sequence. A few years ago, this was changed to an 8 pulse sequence. The special mode run on TIGER allows a comparison of the backscatter for near coincident 7 and 8 pulse sequences. The results are presented by range gate, and show that overall, increased backscatter occurrence for the 7 pulse transmit sequence.



## Double-frequency operation in the AgileDARN

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The AgileDARN is a HF radar located in Jiamusi, China. It is a highly-digitalized radar. The phasing network and fully digital system will be implemented using FPGA technology, which can provide greater flexibility in double-frequency operation. Different from the typical stereo systems, such as CUTLASS, the double-frequency operation in the AgileDARN will be achieved by digital signal processing, without any additional receive channels. By designing the transmitted signals and/or pulse sequence, double-frequency mode will be used to improve range resolution or temporal resolution. Since the system response varies with frequency, internal calibration of the transmitters and receivers at the two frequencies will be done to improve the measurement accuracy. Fulfilling double-frequency operation by signal processing can improve the system performance. Moreover, it can reduce the system complexity and cut the cost.

## Calculating ionospheric plasma densities from SuperDARN dual-frequency velocity measurements using artificial backscatter over EISCAT

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We demonstrate the successful calculation of ionospheric electron number densities derived from quasi-simultaneous line of sight velocity measurements at multiple frequencies from the Cooperative UK Twin Auroral Sounding System (CUTLASS) SuperDARN radar at Hankasalmi. Backscatter was generated using the EISCAT heater. Using ray tracing to obtain the altitude of the backscatter, we verify the SuperDARN electron number densities are consistent with those obtained from the EISCAT incoherent scatter radar at Tromso over the same time period. With SuperDARN's wide field of view and long-range capabilities, this new technique is powerful for calculating electron number densities over a large spatial extent. We also show, for the first time, Hall and Pedersen conductivities over the course of our case study calculated from the SuperDARN derived electron number densities. This will permit global estimates of ionospheric conductivity and Joule heating.

## Preliminary result on the statistical analysis on the effect of energy parameters on HF backscatter

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We present preliminary results of a statistical analysis of the effects of both external and internal drivers on the occurrence of ionospheric scatter and ground scatter from 1996-2015. The data used in our analysis were obtained from the two eastern-most Super Dual Auroral Network (SuperDARN) radars located at Hankasalmi (Finland) and Pykkvibaer (Iceland). We investigate the impact of solar minimum and solar maximum on the effects of the parameters on the occurrence of both ionospheric scatter and ground scatter. We also investigate the effects of the parameters on the amount of backscatter occurrence during the extended solar minimum.



## **Identification of ionospheric electron density changes due to solar flares and energetic particle precipitation using the SuperDARN data**

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Watanabe and Nishitani (Adv. Polar Sci., 2013) showed that during solar flares the SuperDARN data show positive Doppler velocities in ground / sea scatter echoes, and that this velocity change can be interpreted mainly in terms of the abnormal ionization of the D-region ionosphere due to EUV / X-ray, leading to the shortening of the HF ray paths. They also showed that it is possible to identify the plasma density changes from the Doppler velocity distributions. These results suggest that it might be possible to identify the D-region plasma density changes due to energetic particle precipitation events such as substorms using the same technique. Ionospheric convection around substorm expansion onset is characterized by reduction of sheared flow and enhancement of equatorward flows (e.g., Bristow et al., J. Geophys. Res., 2007). However, there have been no studies on the effect of D-region HF wave absorption due to particle precipitation, which could lead to positive Doppler shift, which is independent of beam number but could be positively (negatively) correlated with the range (elevation angle) Initial result of the quantitative estimation of Doppler velocities associated with particle precipitation will be presented.

## **Characterization of Sudden Ionospheric Disturbance (SID) based on statistical analysis of events of Shortwave Fadeout observed in daytime SuperDARN ground-scatter**

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One impact of sudden ionospheric disturbance (SID) is the short wave fadeout (SWF) which occurs on the dayside of the Earth as a result of increased D region absorption following a burst of x-ray flux that is due to a solar flare. Events of SWF occur within minutes of a flare, typically last for tens of minutes to an hour, and are most severe at noon LT. SuperDARN observations of daytime ground-scatter are known to be strongly affected; the number of ground-scatter echoes drops suddenly (~1 min) and sharply, often to near zero (dependent on intensity of solar flare). The recovery is comparatively gradual (10s of minutes). We have analyzed a number of events and report here on the characterization of SWF in SuperDARN observations produced by M and X class solar flares into distinct phases defined by a) Quiet time – preceding period when the number of ground scatter echoes is stable, b) Onset time– just before the fadeout starts, c) Valley start time – event hits maximum intensity, d) Valley end time – start of recovery, and e) Recovered time – time of return to pre-event ground scatter numbers. We use pattern recognition techniques to determine the phases and to identify the velocity ‘flash’ in the ground scatter that precedes the dropout in ground scatter number. We also characterize events in terms of intensity and duration based on transmitted frequency, latitude, and solar zenith angle and we examine the timing of SWF across the dense sub-network of SuperDARN radars in North America. We describe the development of a Python-based tool that can monitor real-time observations and detect the onset of SWF. We discuss the pattern recognition technique, the results of statistical characterization of SWF in SuperDARN observations, and the development of an effective space weather capability for detecting this source of disruption to HF communication channels.



## **Solar control of F-region radar backscatter: Further insight from observations in the southern polar cap**

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The role of solar wind and illumination in production of small-scale F-region plasma irregularities is investigated using a 4-year data set collected by the Super Dual Auroral Radar Network (SuperDARN) facility at the McMurdo station, Antarctica (MCM). Statistical analysis of ionospheric echoes detected by MCM shows that radar backscatter from the polar F region occurs in wide and persistent bands that exhibit systematic changes with local time, season, and solar cycle. It is demonstrated that all variations considered together form a distinct pattern. A comparison with F region model densities and raytracing simulations shows that this pattern is largely controlled by the F region solar-produced ionization during the day. During the night, however, MCM observations reveal a significant additional source of plasma density in the polar cap as compared with the model. An example of conjugate radar observations is presented that supports the idea of polar patches being this additional source of ionization on the nightside. Echo occurrence within the band exhibits a clear peak near the solar terminator, which suggests that small-scale irregularities form in turbulent cascade from large scales. Further, echo occurrence is enhanced for particular IMF orientations during the night. Observations indicate that solar illumination control of irregularity production is strong and not restricted to the nightside. Indirect solar wind control is also exerted by the IMF-dependent convection pattern, since the gradient-drift instability favors certain orientations between the plasma density gradients and convection velocity.

## **Causes of HF backscatter fadeout: A study of SuperDARN data during intense geomagnetic storms**

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SuperDARN radars are known to experience backscatter fadeout during geomagnetic storm events. The backscatter occurrence during 25 storm events was examined using a storm phase based epoch analysis. Backscatter fadeout in range gates beyond 15 was consistent with published literature. However, an increase in close range backscatter was observed during storm main and recovery phase. These ranges are usually associated with backscatter from E region altitudes. This is inconsistent with D region absorption of HF signals. Ionosonde data, riometer data and raytracing simulations were used to infer ionospheric properties during different storm phases. The observed close range echoes and the loss of backscatter in further ranges during storm events will be explained in the context of these combined data sets.



## Dual radar investigation of E-region plasma waves in the southern polar cap

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Origins and characteristics of small-scale plasma irregularities in the polar ionosphere are investigated using a dual radar setup in which the E region is probed from opposite directions by two SuperDARN radars at MCM and Dome C Antarctic stations. In certain time intervals, velocity agreement is observed when velocities are compared at the same physical location in the horizontal plane. Such an agreement is widely expected if velocity at a given location is largely controlled by the convection electric field. In other cases, however, velocity agreement is unexpectedly observed when measurements are considered at the same slant range for both radars. This implies that it is not the electric field at a given location that is a controlling factor. The observed E-region velocity in the polar cap is demonstrated to depend indirectly on the plasma density distribution, which is important for establishing the fundamental dependence on the convection electric field.

## Large-scale ultra-low frequency waves in the southern polar cap

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Ultra-low frequency (ULF) Doppler velocity oscillations have been detected in the southern polar ionosphere using data from the McMurdo, Dome C East and South Pole Station SuperDARN radars. The 1.0-1.3mHz oscillations are believed to have occurred on open magnetic field lines where the simple field line resonance interpretation of ULF waves may not apply. The oscillations were accompanied by a coherent ground magnetometer signature from deep within the polar cap and also by field line resonance activity in the dayside auroral zone. In this talk we investigate the spatial properties and possible sources of the polar cap oscillations, and their relationship to auroral-latitude ULF waves.

## SuperDARN convection models: Past, present, and future

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The Super Dual Auroral Radar Network (SuperDARN) is widely lauded for its ability to produce two-dimensional maps of global ionospheric plasma convection as contours of electrostatic potential. These global maps are most commonly produced by first combining line-of-sight velocity measurements onto an equal area magnetic grid and then fitting the data to a spherical harmonic expansion of the ionospheric electrostatic potential, known as the Map Potential technique. A statistical model is used to supplement regions of sparse radar coverage to ensure the potential solution remains realistic. Since the creation of the first statistical model nearly two decades ago, updated models have been produced with some regularity as the SuperDARN array continues to expand across both the Northern and Southern hemispheres. In this presentation we will review the features and limitations of prior statistical SuperDARN convection models. Next we will address the current utilization and availability of these models within the SuperDARN community and beyond. Finally, we will discuss considerations for the development of a new statistical model which will include observations from the new tiers of recently constructed radars at midlatitudes and in the polar cap.



## Characterizing the spatio-temporal response of high latitude convection using SuperDARN, DMSP, and ACE

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High latitude convection is a highly variable system in time influenced by multiple processes, presenting a significant challenge when trying to isolate the response to only one of these inputs. We will present a data based method that can isolate systematic variations within the incomplete convection information provided by SuperDARN and DMSP as well as measurements of space weather parameters in time over an 11 year solar cycle. These variations are condensed into a limited set of basis functions with corresponding amplitudes in time that best reproduce the long term data set, in effect producing an estimate of convection at all locations ever measured by SuperDARN or DMSP and at all times over the solar cycle. Initial results demonstrating the successful assimilation of polar cap convection measurements, including single Line of Sight (LOS) drift measurements, will be shown.

### Solar cycle variations in SuperDARN data

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We will analyse variations in SuperDARN data over nearly two decades, investigating variations both in the convection maps and in the data coverage from individual radars in the northern and southern hemispheres.



## Large scale coordinated observations of Pc5 pulsation events

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HF radars belonging to the SuperDARN network receive backscatter over substantial fields of view which, when combined, allow for simultaneous returns over extensive regions of the polar caps and mid-latitudes. This makes them ideal instruments for the observation of pulsations in the Pc5 frequency band. Relatively few pulsation events observed by multiple radars have been reported in the literature. Here we describe observations of three such events which extend over more than  $120^\circ$  of magnetic longitude in the northern hemisphere and which, in one case, is also detected in the southern hemisphere. All three events show characteristics of field line resonances. In one case the pulsation has also been observed by magnetometers under or near the radar fields of view. The extensive longitudinal coverage allows accurate determination of azimuthal wave numbers. These are at the upper end of the lower values associated with external sources such as those in the solar wind. Such sources imply antisunward flow. However, the azimuthal wave number is negative implying westward propagation at magnetic local times on both sides of noon, as would be expected from drift-bounce resonance with positive particles. Quiet conditions and very low ring current during the events argues against this. The identification of the source of pulsations from a number of different mechanisms remains a problem of interest.

## Simultaneous ground and satellite observations of throat aurora

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Throat aurora is suggested to be formed at equatorward of the east-west aligned persistent cusp aurora when the magnetospheric cold plasma flowing into the magnetopause reconnection site [Han et al., 2015]. In this paper, a sequence of approximately south-north oriented throat auroras successively configured in the post-noon and drifted towards magnetic noon was observed over Svalbard on December 27, 2003. Simultaneous ground measurements of 630.0 nm auroral emission and ionospheric backscatter made by all-sky images and Finland HF radar indicate that the transient brightening of the throat aurora is largely co-located with the enhanced spectral width at equatorward of the convection reversal boundaries, whereas the co-located HF radar backscatter turns into sporadic when the throat aurora becomes dim or narrow. By examining particle data from the spacecraft NOAA-16 and DMSP F16 when they overflight the throat aurora, we confirm that the brightening throat aurora is associated with a population of the injected magnetosheath particles mixed with the trapped magnetospheric plasmas, which is connected to low-latitude boundary layer suggests on the open field lines. However, it is proposed that the throat aurora associated with sharply decreased Rayleigh intensities, traced by DMSP fluxes, occurred on the newly closed field lines. The burst throat aurora associated with the following poleward-moving auroral forms, leads us to propose that the localized magnetic topology relates to the throat aurora observations should be substantially changed. The throat aurora as one of significant auroral phenomenologies is thus believed to be related to the dynamic nature of energy and momentum transfer from solar wind into magnetosphere through transient magnetic reconnection.



## Hemispheric asymmetry of the structure of dayside auroral oval and distribution of dayside auroral morphology

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A comprehensive analysis of long-term and multi-spectral auroral observations made in the Arctic and Antarctica demonstrates that the dayside auroral ovals in two hemispheres are both presented a two-peak structure, namely the prenoon 09:00 MLT and postnoon 15:00 MLT peaks. The two-peak structures of dayside ovals, however, are asymmetric in two hemispheres, i.e., the postnoon average auroral intensity is more than the prenoon one in the northern hemisphere, but less in the southern hemisphere. The hemispheric asymmetry cannot be accounted for by the effect of the IMF By component and the seasonal difference of ionospheric conductivities in two hemispheres, which were used to interpret satellite-observed real-time auroral intensity asymmetries in the two hemispheres in previous studies. We suggest that the hemispheric asymmetry is the combined effect of the prenoon-postnoon variations of the magnetosheath density and local ionospheric conductivity. In addition, using the LBP-based representation method plus the k-nearest neighbor classifier, a statistical contrastive analysis of the dayside auroral morphology distribution in northern and southern hemispheres, specifically, auroras observed at Yellow River Station (YRS) and South Pole Station (SPS) is made. Experimental results show that, the four auroral types present very similar occurrence distribution in the two stations, but there are still some differences. We suggest that these differences of occurrence distribution are also related with the local ionospheric conductivities in the two stations.

## Design of upgraded antenna for Syowa radars

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Antarctic SENSU Syowa South and East radars have been running since 1995 and 1997, respectively. Many maintenance works for conventional log-periodic antennae have been required almost every year mainly due to bent or broken elements, saddles (parts connected to elements and phase lines) and so on. To overcome the situation, improved versions of essential parts particularly related to elements have been developed and introduced and antennae have worked well for about 20 years. But we recently encountered 2 incidents where the frame of the antenna boom was bent probably due to metallic fatigue from long-year usage. Therefore we have decided to upgrade our antenna arrays to achieve easier and much less maintenance works at Syowa as well as better performance of the antennae for longer years. We plan to upgrade to King Salmon type of log-periodic wire antenna for the purpose after comparing with possible usage of TTFD antenna. As the ground form around the antenna sites are not necessarily flat, it is better to estimate the influence of the non-flat ground and to determine the best design for the new wire antenna. We've performed to calculate a realistic antenna pattern and tried to finalise the design. Detailed simulation results and the design will be discussed, to share our idea for similar situations possibly encountered by older radars in some future.



## **HF radar observations of a Quasi Biennial Oscillation in mid-latitude mesospheric winds**

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The Equatorial Quasi Biennial Oscillation (QBO) is known to be an important source of interannual variability in the mid and high-latitude stratosphere. The influence of the QBO on the stratospheric polar vortex in particular has been extensively studied. However, the impact of the QBO on the winds of the mid-latitude mesosphere is much less clear. We have applied 13 years (2002-2014) of data from the Saskatoon HF radar to show that there is a strong QBO signature in the mid-latitude mesospheric winds during the late winter months. We find that the Saskatoon mesospheric winds are related with the winds of the equatorial QBO at 45 hPa, such that the westerly mesospheric winds strengthen when QBO is easterly and vice-versa. We also consider the situation in the late-winter Saskatoon stratosphere using the ECMWF ERA-Interim reanalysis data set. We find that the Saskatoon stratospheric winds between 5 hPa and 70 hPa weaken when the equatorial QBO at 45 hPa is easterly and vice-versa. We speculate that gravity wave filtering from the QBO-modulated stratospheric winds and subsequent opposite momentum deposition in the mesosphere plays a major role in the appearance of the QBO signature in late winter Saskatoon mesospheric winds, thereby coupling the equatorial stratosphere and mid-latitude mesosphere.



## Methods for estimating regional auroral electron energy deposition from ground-based optical measurements

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Auroral electron precipitation forms a complex and dynamic energy input into the high-latitude ionosphere and thermosphere. Rapid changes in plasma density due to electron impact ionization create correspondingly rapid changes in conductivity which in turn change the magnitude and altitude profile of magnetospheric current closure in the E- and F-region. Modeling these changes in the ionosphere and their effects on current closure requires detailed input over wide regions. In support of the AMISR PINOT campaign and several rocket campaigns (CASCADES-2, MICA, ASSP) we have investigated several methods using purely ground-based optical measurements to determine the characteristics of auroral input in geometries away from magnetic zenith. The use of the N<sub>2</sub><sup>+</sup> first negative emissions at 427.8 nm reproduces the total energy flux over a wide region, but alone does not indicate the altitude profile of this energy deposition. Determining the energy distribution of the precipitating electrons via automation has been more difficult, especially when observing away from magnetic zenith. We describe two basic methods and discuss their strengths and weaknesses. One method is to use altitude profiles of specific emissions and match them to altitude profiles calculated from electron transport models. The incident electron distribution can be estimated by varying the energy distribution used in the model and determining the best match to the observed profile. The second method makes use of the temperature variations observed in a wide-field Fabry-Perot interferometer (Scanning Doppler Imager, SDI) when observing the atomic oxygen green-line emission (557.7 nm). The rapid variations in temperature observed by the SDI during active aurora is due to variations in emission altitude (due to average energy variations) sampling along the steep temperature curve of the lower thermosphere. By comparing the measured temperature to a model temperature profile (MSIS) the emission altitude is found and matched to emission profiles calculated with an electron transport code. Comparing both methods to in-situ and ISR measurements show that the profile method is more accurate, but is harder to automate. A successful automated method for producing energy deposition maps of reasonable resolution over a wide geographic area will certainly require a hybrid of ground-based and orbital optical data as well as in-situ particle measurements, and ISR data.



## Possible correlation of GPS scintillation data and SuperDARN data at polar latitudes

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High levels of scintillation caused by strong magnetic storms can cause GPS devices to lose connection with the necessary satellites. Research has shown a correlation between major magnetic storms and higher levels of the recorded scintillation and Total Electron Content (TEC) seen in GPS receivers. This research examines if SuperDARN data can be used to predict scintillation levels in GPS receivers at polar latitudes. Using GPS values sigma phi, S4 and TEC that were collected from December, 2013 till November, 2015. The sigma phi, and S4 values were gathered from both Poker Flat, Alaska and McMurdo Station, Antarctica. While the TEC values were only collected from Poker Flat. By using various graphical methods the GPS data was then compared with the recorded velocity, power and spectral width measurements from Kodiak, Alaska, and South Pole, Antarctica, SuperDARN sites. The SuperDARN values were ignored in the comparison if they did not fall within the specified GPS field of view or were tagged with a ground scatter flag or a quality of data flag. The plots of the northern latitudes show GPS scintillation values centering around zero for all SuperDARN value types. Southern latitude plots show lower scintillation levels recorded in general, with a lower correlation with SuperDARN. Based on these results SuperDARN cannot be used to predict higher levels of GPS scintillation in polar latitudes.

## Hardware and software design for dual polarization measurements at Kodiak

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We are developing an upgrade to the Kodiak SuperDARN radar to provide two independent transmit and receive paths for each antenna. When combined with dual polarization antennas, this will enable electrical steering of the polarization of transmitted pulses and polarization information on received scatter. Additionally, the redesigned RF front end improves the linearity and maximum supported pulse duration compared to the MSI design. This poster presents an overview of the hardware and software design for upgraded Kodiak transmitters and simulations of a possible dual-polarization retrofit for Sabre log periodic dipole array antennas.

## Survey of SuperDARN elevation angles

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Nearly all SuperDARN radars are equipped with secondary arrays in order to make interferometer measurements and estimate the elevation angle of backscattered signals. It is becoming more apparent that these measurements are critical for identification of the correct propagation mode, accurate geolocation of backscatter and velocity correction estimation. The elevation angle, however, has been used in relatively few studies and is generally not considered to be a fundamental measurement on par with Doppler velocity, power and spectral width. Currently, many radars do not collect XCF data and for some that do there appear to be calibration issues. The purpose of this presentation is to discuss issues related to elevation angles and the ability of the network to make these measurements.



## **Analysis of the decameter E-region irregularities and the plasma convection in the southern hemisphere**

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The relationship between characteristics of small-scale ionospheric irregularities in the polar and auroral E-region and the plasma convection in F-region is investigated using SuperDARN radars at high southern latitudes. Detailed correlation analysis is performed to investigate the dependency of the occurrence of high-velocity E-region echoes ( $>200$  m/s) upon the occurrence of the convection component with velocity exceeded the ion-acoustic speed. It is found that occurrence of the E-region echoes with highly positive and highly negative velocities exhibits well-defined seasonal and diurnal pattern with high asymmetry between two velocity polarities. Notably, this asymmetry is not due to the asymmetry in the direction of the convection. The growth rate modeled based on the convection velocity shows high correlation with occurrence of negative velocities for DCE, SPS, and ZHO radars and high correlation for positive velocities for MCM and SYE. The radar groupings can be explained in part by their orientation relative to predominant convection pattern, with an overall asymmetry in E-region velocities being much stronger than that seen in the plasma convection.

## **A modeling study of asymmetries in plasma irregularity characteristics near gradient reversals**

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Asymmetries in plasma density irregularity generation between the leading and trailing edges of the large-scale plasma density structures in the high-latitude ionosphere are investigated. A model is developed that evaluates the gradient-drift instability (GDI) growth rate differences across the gradient reversal that is applicable at all propagation directions and for the broad range of altitudes spanning the entire lower ionosphere. In particular, the model describes asymmetries that would be observed by an oblique scanning radar near density structures in the polar cap such as polar patches and sun-aligned arcs. The dependencies on the relative orientations between the directions of the gradient reversal, plasma convection, and wave propagation are examined at different altitudinal regions. At all altitudes, largest asymmetries are expected for observations along the gradient reversals, e.g. when an elongated structure is oriented along the radar boresite. The convection direction that results in the strongest asymmetries exhibits a strong dependence on the altitude, with the optimal convection being parallel to the gradient reversal in the E region, perpendicular to it in the F region, and at some angle between these extremes in the transitional region. Implications for observations of polar patches and sun-aligned arcs by oblique scanning radars within the Super Dual Auroral Radar Network are discussed. It is demonstrated that the wave propagation direction relative to the prevalent convection and gradient directions plays a critical role in controlling both the irregularity growth rate and its asymmetries near gradient reversals.



## **SuperDARN investigations of an unusual sporadic-E layer as a result of a missile destruction**

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On 9 December 2009, as a result of technical problems during a test launch a solid propellant military missile self-destructed over the Kola Peninsula at an altitude of some 200 km. Ionosonde and meteor scatter radar observations at Sodankyla Geophysical Observatory (SGO) have been reported by Kozlovsky et al. (2014) who demonstrated that products of the explosion had several geophysical effects in the upper atmosphere. About 2 hours after the explosion the meteor scatter radar observed increased backscatter signals, while about 3 hours later a clear sporadic-E layer was observed by the ionosonde. Using the Hankasalmi SuperDARN we investigate the spatial and temporal evolution of the sporadic E-layer.

## **Nighttime PolarDARN E-region echoes in the presence of sporadic E layers**

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Occurrence of E-region echoes in the northern polar cap is very limited during nighttime because of poor geometric aspect angles and low electron density in the dark ionosphere. We investigate a special class of PolarDARN echoes observed in the presence of strong sporadic E layers enhancing ionospheric refraction and even blocking HF radio wave penetration into the ionosphere. The focus is on joint observations of the Clyde River radar and Pond Inlet CADI ionosonde. We assess echo power, Doppler velocity and spectral width for such echoes and compare them with the same characteristics for other SuperDARN radars. We conclude that the only clearly identifiable difference is a complete absence of “super Cs” echoes with velocities above 500 m/s, the nominal ion-acoustic speed of the plasma.



## **GPS phase scintillation during the geomagnetic storm of March 17, 2015: The relation to auroral electrojet currents**

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Ionospheric irregularities cause rapid fluctuations of radio wave amplitude and phase that can degrade GPS positional accuracy and affect performance of radio communication and navigation systems. The ionosphere becomes particularly disturbed during geomagnetic storms caused by impacts of coronal mass ejections compounded by high-speed plasma streams from coronal holes. Geomagnetic storm of March 17, 2015 was the largest in the current solar cycle. The high-latitude ionosphere dynamics is studied using arrays of ground-based instruments including GPS receivers, HF radars, ionosondes, riometers and magnetometers. GPS phase scintillation index is computed for L1 signal sampled at the rate of 50 Hz by specialized GPS scintillation receivers of the Expanded Canadian High Arctic Ionospheric Network (ECHAIN). To further extend the geographic coverage, the phase scintillation proxy index is obtained from geodetic-quality GPS data sampled at 1 Hz. In the context of solar wind coupling to the magnetosphere-ionosphere system, it has been demonstrated that GPS phase scintillation is primarily enhanced in the cusp, tongue of ionization (TOI) broken into patches drawn into the polar cap from the dayside storm-enhanced plasma density (SED) and in the auroral oval during energetic particle precipitation events, substorms and pseudo-breakups in particular. In this paper we examine the relation to auroral electrojet currents observed by arrays of ground-based magnetometers and energetic particle precipitation observed by DMSP satellites. Equivalent ionospheric currents (EICs) are obtained from ground magnetometer data using the spherical elementary currents systems (SECS) technique developed by Amm and Viljanen (1999) that has been applied over the entire North American ground magnetometer network by Weygand et al. (2011).

References: Amm, O., and A. Viljanen, *Earth Planets Space*, 51, 431–440, 1999. Weygand et al., *J. Geophys. Res.*, 116, A03305, 2011.



## A comparison between large-scale irregularities and scintillations in the polar ionosphere

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A comparison between large-scale ionospheric irregularities recorded in the Global Positioning System total electron content (TEC) and scintillations observed by Canadian High Arctic Ionospheric Network are pursued during a geomagnetic storm. Irregularities, such as storm enhanced density (SED), middle-latitude trough and polar cap patches, are clearly identified from the TEC maps, together with the modeling auroral oval. At the edges of these irregularities, clear scintillations appeared but their behaviors were different. Phase scintillations were much larger than amplitude scintillations (S4) both in the SED segmented area and at the equatorward edge of the middle-latitude trough in post-noon sectors, associated with the bursty flows or flow reversals. S4 and phase scintillation were small in the polar cap with small enhancements due to the varied flows with the density gradient at the edges of polar cap patches. While S4 were much larger than phase scintillations in the auroral oval mainly due to the particle precipitations.

## On the observed dissipation of F-region FAI after cessation of heating

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The spectrum of field-aligned irregularities produced in HF ionospheric heating has a shape predicted by a number of authors, with different wavelength regimes examined theoretically using various applicable approximations. At the smallest scales (< a few ion gyroradii), thermal fluctuations are excited creating cross-field density gradients, which lead to linear conversion of the heater pump wave to upper hybrid waves [eg. Dysthe et al., 1982]. At longer scales, thermal-self focusing of the heater beam leads to irregularities with scales on the order of 10s of meters and larger. Self-focusing occurs when the irregular electron density leads to refraction of the heater beam towards regions of low density and increases the heating there. The increased heating leads to increased diffusion out of the low-density regions, reinforcing the refraction into the region. While much attention has been devoted to the formation of irregularities in heating experiments, very little work has been done to examine their decay after heating ceases. Similar to previous HF radar observations [Hysell, 1996] SuperDARN observations show that the irregularities decay in a two-time-scale process. For the first ~10-20 seconds after heating stops, the irregularities decay rapidly (~1dB/s), then a slower decay rate (~0.1 dB/s) takes over and persists. This talk presents observations of HAARP generated irregularities by the Kodiak radar demonstrating the two-time-scale decay, then presents a theoretical discussion on what time scales should be expected. Arguments will be presented that the decay represents the along-field diffusion of the plasma, and hence can be used to derive diffusion coefficients.

Dysthe, K. B., E. Molhus, H. Pesceli, K. Rypdal (1982), Thermal cavitons. Phys. Scr., T2/2, 548-559.  
Hysell, D. L., M. C. Kelley, Y. M. Yampolski, V. S. Beley, A. V. Koloskov, P. V. Ponomarenko, and O. F. Tyrnov (1996), HF radar observations of decaying artificial field-aligned irregularities, J. Geophys. Res., 101(A12), 26981–26993, doi:10.1029/96JA02647.



## Dynamics of plasma convection in the reverse convection region under extreme northward IMF conditions

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Many previous studies have examined how ionospheric convection is tightly controlled by interplanetary conditions. However, less is known about the time-scale on which the convection changes from one state to another, and how this time-scale might be dependent on internal and external conditions. In this study, we analyze an interval of strong northward IMF on September 9th, 2014 which provided a rare opportunity to examine dynamic changes in the dayside reverse convection throat for an extended period of time. Between 18:00 - 20:00 UT the northward face of the Resolute Bay Incoherent Scatter Radar (RISR-N) was located in the noon sector, and directly measured reverse convection in the dayside throat region. Nearly simultaneous measurements from DMSP satellites confirm the reverse convection and the cusp features expected for northward IMF. Time-series comparison of the north-south flows with the IMF Bz component shows a remarkably high correlation, suggestive of very strong linear coupling, with no sign of velocity saturation. Specifically, as the IMF turned northward and then steadily strengthened to 28 nT, the north-south flows responded linearly, peaking at a maximum value of 2800 m/s. Several small and short lived variations in Bz also produced linear responses in the north-south flows. Likewise, the IMF By component was highly correlated with the east-west ionospheric flows measured by RISR-N. However, time-lagged correlation analysis reveals that the IMF By influence acted on a time-scale which was 10 minutes faster than that of the Bz component. We attribute this difference in the Bz/By time-scales to simultaneous occurrence of antiparallel merging at the poleward of the cusp and the component merging at the subsolar magnetopause.



## Joint RISR-SuperDARN study of the plasma throat during a poleward excursion of the IMF Bz

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Magnetic activity was quiet on the very first day of combined RISR-C and RISR-N observations on August 29, 2015. In spite of a less than 40 kV cross-cap potential, a keogram obtained from the two RISR radars revealed that the flow was generally anti-sunward over the polar cap region with target motion speeds of the order of 600 m/s. However, this general trend was interrupted near the local noon hours, during a northward excursion of the order of 5 nT in the IMF Bz at a time when the IMF By was sustained and negative and also of the order of 5 nT. At that point there was a very strong dawn-to-dusk rotation in the convection pattern equatorward of Resolute Bay with the convection throat region moving poleward from a latitude of the order of 75 degrees magnetic latitude to one much closer to Resolute Bay, coming up to 81 degrees magnetic latitude. Fast convection was detected by RISR-C beams pointing toward the dawn sector and also showed that the dawn to dusk flows in that sector. In excellent agreement with this, the SuperDARN radar data, which came mostly from Clyde River, showed that the throat region was indeed strongly skewed toward the dawn sector near Resolute, with flows of the order of 1000 m/s along the dawn-to-dusk direction. The line-of-sight RISR-C ion temperatures in that same region approached 3000 K while the plasma density was also much smaller in the hot regions, probably owing to hot ion chemistry. For this episode, the strong flows stopped when the IMF By weakened. This study indicates that even when the polar cap region is reduced in size, with a minimal cross-cap potential and a relatively weak IMF, there are sustained localized regions of fast convection which respond to the solar wind input, particularly in the throat region. The rest of the polar cap region, however, seemed to continue to show antisunward flows of the order of 600 m/s, at least according to the keograms.

## Dawn-dusk asymmetry of SI-associated transient ionospheric convection oscillation

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The statistics based on SuperDARN (SD) observations revealed that the transient oscillation of ionospheric convection associated with sudden impulses (SIs) showed some dawn-dusk asymmetric structures. The previous study showed that the higher latitude portion of the twin vortex-shaped convection perturbation has a dawn-dusk asymmetry depending on the combination of IMF-By polarity and SI polarity. In addition to the asymmetry depending on IMF-By polarity, the lower latitude portion of the induced twin vortices has a dawn-dusk asymmetry in such a way that the dawn side flow perturbation is always weaker than the dusk side one. Interestingly, our statistical study shows that this feature does not depend on either the IMF-By polarity or SI polarity, existing more or less for all conditions. This fact suggests that a different mechanism causes the difference in flow magnitude of lower latitude side of vortices between dawn and dusk. We perform a set of global MHD simulation runs to examine physical mechanisms causing the response of ionospheric convection associated with SIs. The simulations basically reproduce a weaker flow at the lower latitude portion of the dawn-side vortex, quite similar to those observed by SD. In addition to the realistic situations, a simulation run without the ionospheric Hall conductance (only with finite Pedersen conductance) shows a fairly dawn-dusk symmetric pair of flow vortices. This result strongly suggests that the Hall current closure in the ionosphere plays an important role in causing the dawn-dusk asymmetry of the vortex pair induced by SIs.



## The diffraction of power in the polar ionosphere

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Waves in the space environment can interact with the polar ionosphere transferring some or all of this power into the ionosphere. We present a calculation of the wave impedance of the polar ionosphere and use this impedance in standard network theory to calculate the spectrum of power transmitted into the polar ionosphere. The polar ionosphere impedance is calculated by using the electromagnetic field definitions of impedance and the commonly accepted distribution of electric and magnetic fields in the polar ionosphere. The accuracy of this impedance calculation will be demonstrated via comparison of theoretical, experimental, and numerical results. The calculated transmitted power will be compared to measurements of both the Earth and Sun.

## High frequency groundscatter over Hankasalmi

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The polar ionosphere is a dynamic region that readily responds to changes in solar irradiance, solar wind, the magnetosphere, and the neutral atmosphere. The Super Dual Auroral Radar Network (SuperDARN) observes the high-latitude ionosphere using coherent scatter High Frequency (HF) radars. SuperDARN has been operational over one and a half solar cycles, and so provides an invaluable dataset for studying long-term ionospheric variability at high latitudes. Groundscatter, the backscatter that returns from a reflection point on the ground rather than from an ionospheric irregularity, provides a measure of the ionospheric density along the propagation path of the radar signal. We have seen that the amount of groundscatter observed at the Hankasalmi radar changes dramatically with season and solar cycle, with the strongest solar cycle dependence seen during the December solstice. This study examines the solar cycle and local time differences in groundscatter propagation characteristics.



## Multi-instrument studies of thermospheric weather above Alaska

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Earth's thermosphere is comprised of multiple neutral and ionized chemical species. Even over restricted regional areas, current observational capabilities are inadequate to fully characterize both its dynamics and the associated fields that drive its motion. Nevertheless, progress is being made. Here we describe how local-scale coupling between ion and neutral velocity fields can be studied using a combination of SuperDARN radars, an array of ground-based Fabry-Perot spectrometers, ground-based all-sky cameras, the PFISR radar, and satellite based ultraviolet imaging. Data are presented as ion and neutral velocity fields overlaid onto maps of auroral emission brightness across a region that spans much of the main body of the state of Alaska. Temporal and spatial resolution varies by data source, but typically we can resolve features down to around 100 km spatially, and one to two minutes temporally. Results show that, at least for auroral latitudes, winds in the neutral thermosphere respond to magnetospheric drivers with much shorter length and time scales than expected from theory, and that these effects penetrate into the thermosphere down to altitudes as low as 120 km.

## Sources and characteristics of Medium Scale Traveling Ionospheric Disturbances observed by High Frequency radars in the North American sector

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Medium Scale Traveling Ionospheric Disturbances (MSTIDs) are wave-like ionospheric perturbations routinely observed by high frequency radars. We focus on a class of MSTIDs observed during the winter daytime at high and mid latitudes. The source of these MSTIDs remains uncertain, with the two primary candidates being space weather and lower atmospheric processes. We surveyed observations from four high latitude and six mid latitude SuperDARN radars in the North American sector from November through May of 2012 to 2015. The MSTIDs observed have horizontal wavelengths between  $\sim 150$  to 650 km and horizontal velocities between  $\sim 75$  to 325 m s<sup>-1</sup>. In local fall and winter seasons the majority of MSTIDs propagated equatorward, with bearings ranging from  $\sim 125^\circ$  to  $225^\circ$  geographic azimuth. No clear correlation with space weather activity as parameterized by AE and Sym-H could be identified. Rather, MSTID observations were found to have a strong correlation with polar vortex dynamics on two timescales. First, a seasonal timescale follows the annual development and decay of the polar vortex. Second, a shorter 2–4 week timescale again corresponds to synoptic polar vortex variability, including stratospheric warmings. Additionally, statistical analysis shows MSTIDs are more likely during periods of strong polar vortex. Direct comparison of the MSTID observations with stratospheric zonal winds suggests a wind filtering mechanism may be responsible for the strong correlation. Collectively, these observations suggest that polar atmospheric processes, rather than space weather activity, are primarily responsible for controlling the occurrence of high and mid latitude winter daytime MSTIDs.



## **Longitudinally-propagating ionospheric flow structures observed by SuperDARN during March 17-18, 2015 storm**

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We study an interesting wavy structure of ionosphere flow at sub-auroral latitudes observed by SuperDARN during a magnetic storm on March 17-18, 2015. The main phase of the storm shows at least two step development in Dst and apparently those two steps are associated with a more or less isolated substorm followed by a series of more intense substorms, respectively. The wavy modulation of ionospheric flow actually occurs during the relatively stagnant period between the two substorms. At sub-auroral latitude, the fast eastward flow prevailing from midnight to early morning during the first substorm ceases and subsequently the mid-latitude SuperDARN radars start to see a series of alternate flow reversals of toward-radar flows and away-from-radar flows. Each of the flow reversal structures has a longitudinal wave length of roughly  $\sim 1$ h magnetic local time (MLT) and fairly large peak-to-peak amplitude of several hundreds of m/s. Interestingly, those flow structures pass by the fields of view of the radars one after another, showing a clear westward propagation over a wide MLT range from early morning all the way to midnight. From the radar observation, the propagation velocity is roughly estimated to be  $\sim 2$ -3 km/s. The large propagation speed with the relatively stagnant background flow (less than  $\sim 200$  m/s) indicates that the corresponding westward-eastward electric field is not of the ionospheric origin, but is imposed by the magnetosphere. The westward-propagating speed of  $\sim 2$ -3 km/s in the ionosphere corresponds to an azimuthal speed of  $\sim$  a few tens of km/s at 6 Re in radial distance in the equatorial magnetosphere, comparable with azimuthal drift velocities of tens of keV ions. Thus we infer that the westward-traveling modulation of ionospheric electric field could be the footprint of ULF waves propagating in the anti-sunward direction through the dawnside magnetosphere. Further comparison with in situ observations by inner magnetospheric satellites will be made to test this hypothesis as well as to examine how these propagating structures of ionospheric electric field are generated.



## **Ionospheric convection observed by the SuperDARN Hokkaido Pair of (HOP) radars associated with low-latitude auroras**

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Recent SuperDARN deployment toward lower latitudes made it possible to study ionospheric convection associated with low-latitude auroras (up to below 50 degrees geomagnetic latitude) with high temporal resolution (1 min). In this paper we report on the relationship between the appearance of low-latitude auroras for a few geomagnetic storm events (such as that on March 17, 2015 and on December 21, 2015) and ionospheric convection observed by the SuperDARN Hokkaido Pair of (HOP) radars. Associated with low-latitude auroral emission in the postmidnight sector, there was a sheared flow structure with westward flow equatorward of eastward flow, with the equatorward boundary of auroral emission embedded in the westward flow region. Such kind of flow distribution was also observed with other events such as that on January 20, 2016. The observations suggest that the presence of electric field distribution plays some roles in keeping low latitude auroral emission. Detailed discussion of the relationship between the low latitude auroras and the electric field distribution will be presented.

## **Global Pi2 pulsations observed by THEMIS spacecraft, ground magnetometers, and mid-latitude SuperDARN radars during substorm onset**

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We present simultaneous space and ground-based observations of Pi2 pulsations which occurred during a substorm onset on September 25th, 2014. The expansion phase initiated at around 06:04 UT when the Electric Field Instrument (EFI) and Fluxgate Magnetometer (FGM) aboard the THEMIS probe D (THD) first detected pulsations in the Pi2 frequency range (7-25 mHz). Analysis of the electron density and spacecraft potential data suggests THD was inside the plasmasphere at this time. Cross spectrum analysis shows the azimuthal electric field and compressional magnetic field components oscillated nearly in quadrature, highly suggestive of a radially trapped standing fast mode wave. Spectral analysis of data from widely distributed ground magnetometers showed fundamental and second harmonic spectral peaks in their H and D components. Two separate latitudinal magnetometer chains on the nightside observed polarization changes of Pi2 pulsations when crossing the footprint of the plasmopause ( $L \sim 4.0$ ). Simultaneous Pi2 observations from several low-latitude ground magnetometers (some on the dayside) further illustrate the global nature of these pulsations. Finally, similar pulsation signatures were observed in the Subauroral Polarization Stream (SAPS) flows measured by three midlatitude SuperDARN radars, both poleward and equatorward of the plasmopause footprint latitude. Collectively, these observations are consistent with a Plasmaspheric Virtual Resonance (PVR).



## Simultaneous ground-based optical and SuperDARN observations of the shock aurora

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Using ground-based high temporal and spatial optical aurora observations, we investigated one fortuitous event to illustrate the direct responses of the fine structure auroral emission to interplanetary shock on 7 January 2005. During the shock impact to the magnetosphere, the Chinese Arctic Yellow River Station (YRS) equipped with all-sky imagers (ASIs) was situated at the magnetic local noon region (~1210 MLT) in the Northern Hemisphere, while the SuperDARN CUTLASS Finland HF radar covering the field of view (FOV) of the ASIs at YRS had fine ionospheric plasma convection measurement. We observed that an intensified red aurora manifesting as discrete emission band at higher latitude responds to the shock impact gradually, which results in a distinct broadening of the dayside auroral oval due to the equatorward shifting of its lower latitude boundary after the shock arrival. In contrast, the green diffuse aurora, manifesting as a relatively uniform luminosity structure, reacts immediately to the shock compression, displaying prompt appearance in the southern edge of the FOV and subsequent poleward propagation of its higher latitude boundary. Simultaneously, the CUTLASS Finland radar monitored enhanced backscatter echo power and increased echo number, which coincided with intensified discrete aurora in approximately the same latitudinal region. Doppler velocity measurement showed moving ionospheric irregularities with generally enhanced line-of-sight (LOS) speed, but with prominent sunward flow in the polar cap and antisunward flow in both the eastern and western regions. The SuperDARN global ionospheric convection pattern clearly presented a large-scale plasma flow divided in four circulation cells, with two reversed flow cells nested in the noon sector of the polar cap. These direct observations strongly suggest that the prompt shock compression intensified the wave-particle interaction in the inner magnetosphere and enhanced the lobe magnetic reconnection rate at magnetospheric high latitude.



## Earth's ion upflow associated with polar cap patches: Global and in-situ observations

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We report simultaneous global monitoring of a patch of ionization and in-situ observation of ion upflow at the centre of the polar cap region during a geomagnetic storm. Our observations indicate strong fluxes of upwelling O<sup>+</sup> ions originating from frictional heating produced by rapid antisunward flow of the plasma patch. The statistical results from the crossings of the center polar cap region by DMSP F16 and F17 from 2010 to 2013 confirm that the field-aligned flow can turn upward when rapid antisunward flows appear, with consequent significant frictional heating of the ions, which overcomes the gravity effect. We suggest that such rapidly moving patches can provide an important source of upwelling ions, in a region where downward flows are usually expected. These observations give new insight into the processes of ionosphere-magnetosphere coupling.



## Equatorial ionospheric HF radar: Simulation, design, and plans

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A new SuperDARN style radar is being built in the equatorial zone, as the cornerstone instrument of the planned Kiritimati Equatorial Ionospheric Observatory (KEIO), on Christmas Island, Kiribati. This radar is expected to observe field aligned irregularities associated with plasma bubbles, the equatorial electrojet, and 150km echoes over very long oblique ranges. This system is also expected to observe sea surface Bragg scatter, and to monitor HF propagation conditions. Details of the expected science enabled by this radar will be presented. This new radar system builds on SuperDARN heritage, incorporating a modified antenna TTFD antenna that improves the EIRP of the array, and will utilize low cost COTS digital radios in a MIMO capable imaging array configuration. Details of the antenna and new radio hardware will be presented. Expected performance of this radar has been informed by a full HF radar simulation using the High-frequency Channel Response Function (HiCIRF) tool. This simulation includes the full array geometry and pattern, a full ray tracer, a wind driven sea surface scatter model, and ionospheric irregularities model (WBMOD), an ionospheric drift model (Richmond-NCAR for low-mid latitudes and Heelis-UTD for high latitudes), a noise model (CCIR), a meteor model (driven by MIF), and d-region absorption model. HiCIRF calculates an channel response function through which a simulated HF signal can be convolved to provide simulated I/Q realizations. The simulation results of the equatorial radar will be presented, as will a full 3-D ray trace used to estimate and map regions of expected propagation where perpendicular to B backscatter requirement is met. Under collaboration with the University of the South Pacific (USP), a site for the radar has been selected on Christmas Island (Kiritimati), Kiribati. This site, which will house a future USP teaching and research center, is also planning to host GPS scintillation and TEC receivers, a LEO beacon receiver, UHF scintillation receivers, all-sky optics, and VLF receivers. Details of the site, and a discussion of logistics and construction issues unique to Kiritimati will be presented.



## A link between high-speed solar wind streams and extratropical cyclones

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Databases of extratropical-cyclone tracks obtained from two meteorological reanalysis datasets are used in superposed epoch analysis of time series of solar wind plasma parameters and green coronal emission line intensity. The time series are keyed to times of maximum growth of explosively developing extratropical cyclones during northern and southern winters. The new statistical evidence corroborates the previously published results (Prikryl et al., *Ann. Geophys.*, 27, 1-30, 2009). This evidence shows that explosive extratropical cyclones tend to occur after arrivals of solar wind disturbances such as high-speed solar wind streams from coronal holes when large amplitude magneto-hydrodynamic waves couple to the magnetosphere-ionosphere system. These MHD waves modulate Joule heating and/or Lorentz forcing of the high-latitude thermosphere generating medium-scale atmospheric gravity waves. Ray tracing of aurorally-generated gravity waves show that the gravity waves propagate upward and downward through the atmosphere. Simulations of gravity wave propagation in a model atmosphere using the Transfer Function Model (TFM) (Mayr et al., *Space Sci. Rev.*, 54, 297–375, 1990) show that propagating waves originating in the thermosphere can excite a spectrum of gravity waves in the lower atmosphere. At the tropospheric level, in spite of significantly reduced amplitudes, they can provide a lift of unstable air to release the moist symmetric instability thus initiating slantwise convection and forming cloud/precipitation bands (Prikryl et al., *Ann. Geophys.*, 27, 31-57, 2009). The release of latent heat is known to provide energy for rapid development and intensification of extratropical cyclones. It is observed that severe winter storms caused by low pressure systems tend to follow arrivals of high-speed solar wind. The high- and mid-latitude SuperDARN HF radars observe traveling ionospheric disturbances (TIDs) caused by medium-scale gravity waves that can be traced back to sources at auroral latitudes. When ducted between the lower thermosphere and the Earth's surface, these gravity waves pass through the troposphere. They are the link between the solar wind and the troposphere where they influence development of extratropical cyclones

