First Results of a Fully Digital Auroral Bi-static Radar for Ionospheric E-region Research

D. R. Huyghebaert[1], G. C. Hussey[1], J. P. Vierinen[2], J. P. St-Maurice[1], and K. A. McWilliams[1]

[1]Department of Physics and Engineering Physics, University of Saskatchewan, Saskatoon, Canada
[2]Department of Physics and Technology, University of Tromsø, Tromsø, Norway

University of Saskatchewan

CEDAR Workshop 2018
25–29 June, 2018 Santa Fe, NM
Paper: ITIT-08 Date: 27 June Email: devin.huyghebaert@usask.ca

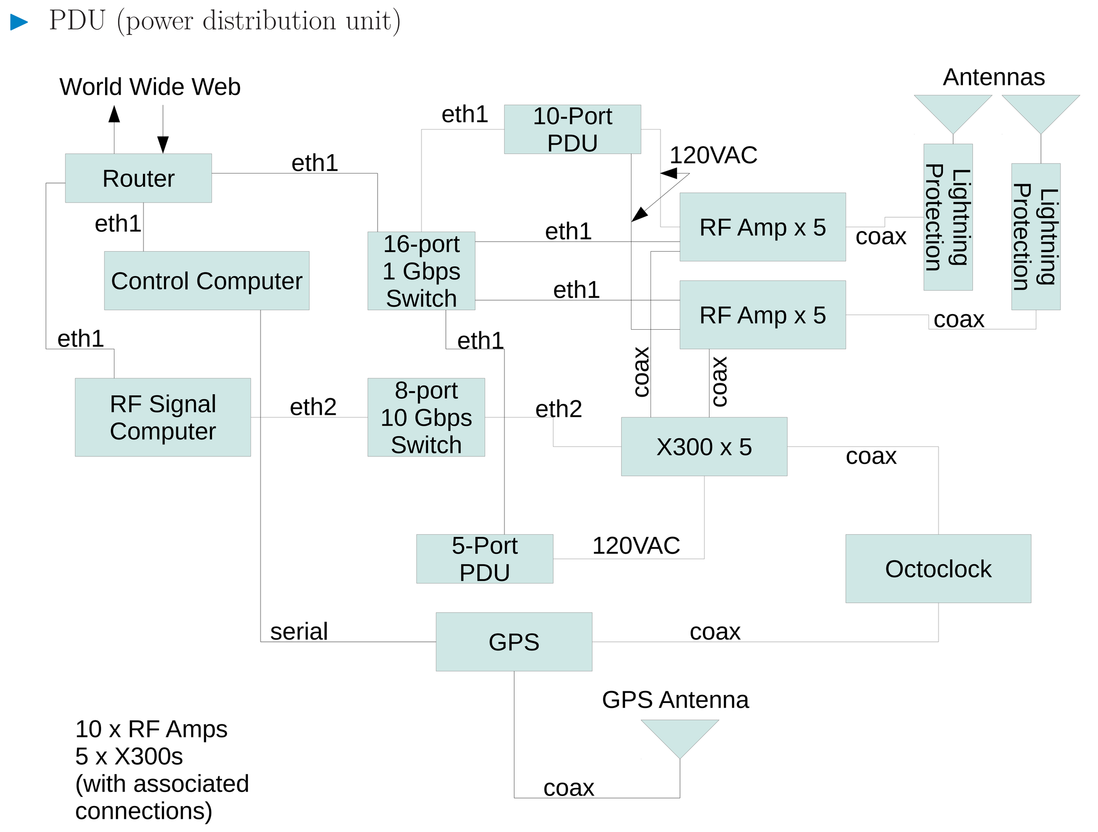
Abstract

The Ionospheric Continuous-wave E-region Bi-static Experimental Auroral Radar (ICEBEAR) has been in operation since December, 2017. It transmits a CW (continuous wave) phase modulated signal, with a center frequency of 49.5 MHz, to obtain simultaneous high temporal (100 ms) and spatial (1.5 km) resolution images of the auroral ionospheric E-region. The bi-static configuration of the radar system allows for continuous transmission and reception of the radar signal, providing a continuous sampling of the E-region in the field-of-view of the radar. The receiver site is located to the north-east of the University of Saskatchewan in Saskatoon, Canada, while the transmitter site is located approximately 240 km south-west of the receiver site. Timing, and hence radar temporal coherence, between the sites (hardware) is synchronized using GPS regulated 10 MHz and PPS signals. Now that the ICEBEAR radar is operational, investigations into E-region plasma instabilities and Magnetosphere-Ionosphere (MI) coupling has been initiated, and is giving highly detailed and interesting results. The ICEBEAR field-of-view is 400 km x 600 km, centered at (57N, 107W) geographic coordinates, observing the auroral zone in western North America. The initial findings from ICEBEAR will be presented, with an emphasis on E-region instability observations.

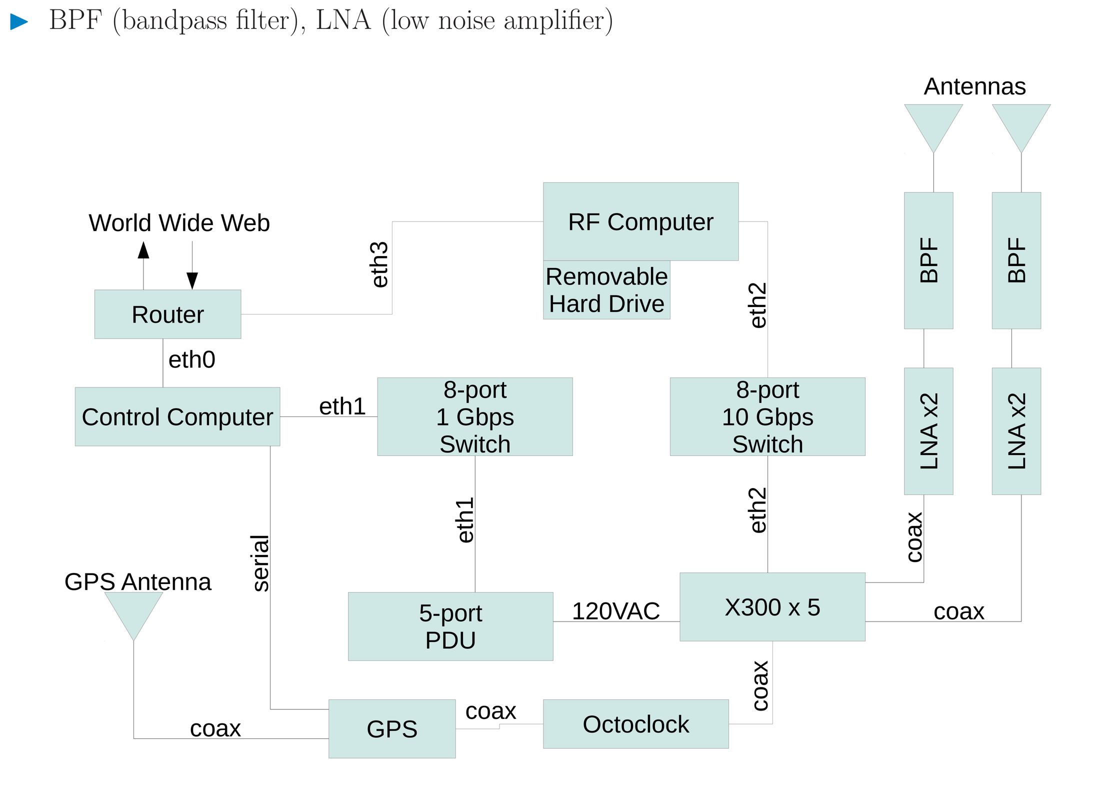
ICEBEAR System Overview

- The Ionospheric Continuous-wave E-region Bistatic Experimental Auroral Radar (ICEBEAR)
- Fully Digital, CW, Bistatic, ionospheric E-region Radar Operating at 49.5 MHz
- Based on software defined radio and USRP (universal software radio peripheral) hardware
- First light in December, 2017
- 10 antenna transmitter array with 600 W on each antenna (completely configurable)
- 10 antenna receiver array images E-region of ionosphere using scattered transmitted signal
- Bistatic system with Tx and Rx isolated by ≈ 240 km
- Tx and Rx time coherent using GPS synchronized clocks
- Bandwidth of signal is 100 kHz (160 kHz band available)
- 1.5 km range resolution and down to 100 ms time resolution simultaneously
- Received signal is directly digitized from each antenna, allowing for extensive post processing
- Remotely Operated

- Transmitter Block Diagram
- PDU (power distribution unit)

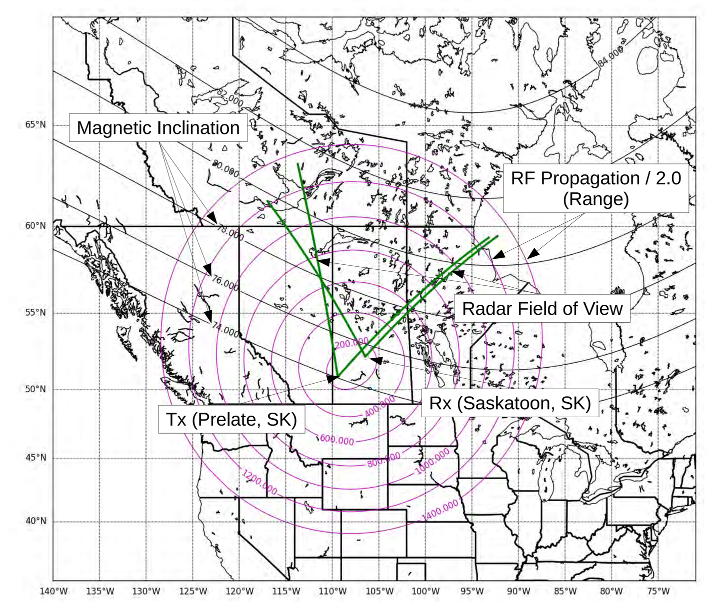


- Receiver Block Diagram
- BPF (bandpass filter), LNA (low noise amplifier)

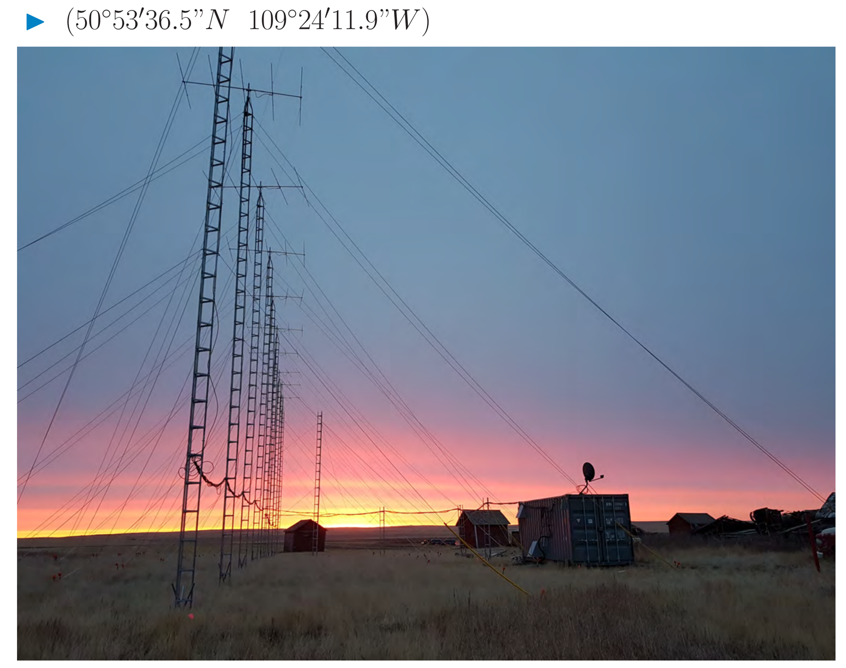


Transmitter and Receiver Locations

- Rx located near Saskatoon, SK
- Tx located near Prelate, SK
- Using a CW signal would saturate receiver on monostatic system



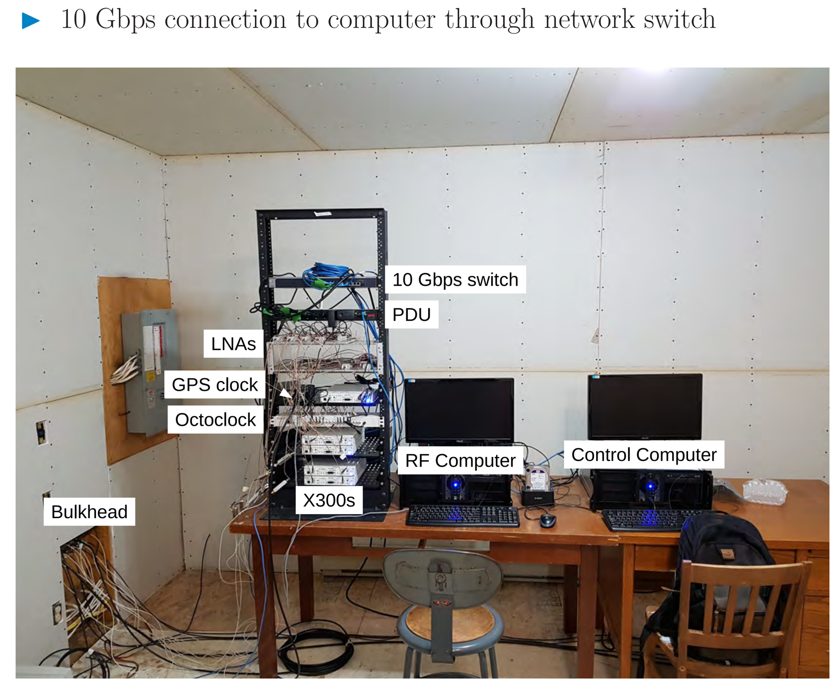
- Transmitter Site (N of Prelate, SK)
- (50°53′36.5″N 109°24′11.9″W)



- Receiver Site (NE of Saskatoon, SK)
- (52°14′38.1″N 106°27′00.9″W)

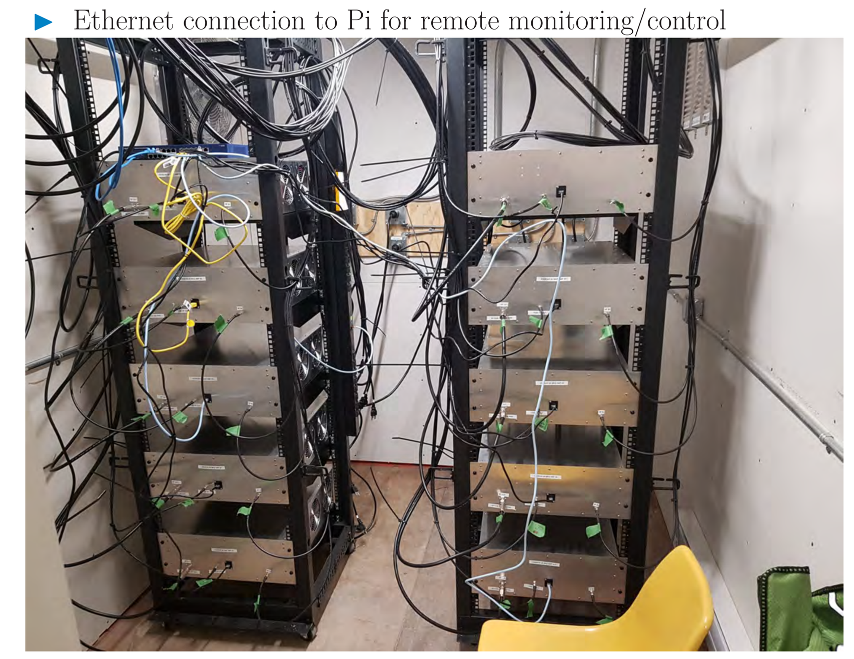
The Receiver Electronics

- X300 Transceivers used with Fury GPSDO for time syncronization
- 10 Gbps connection to computer through network switch

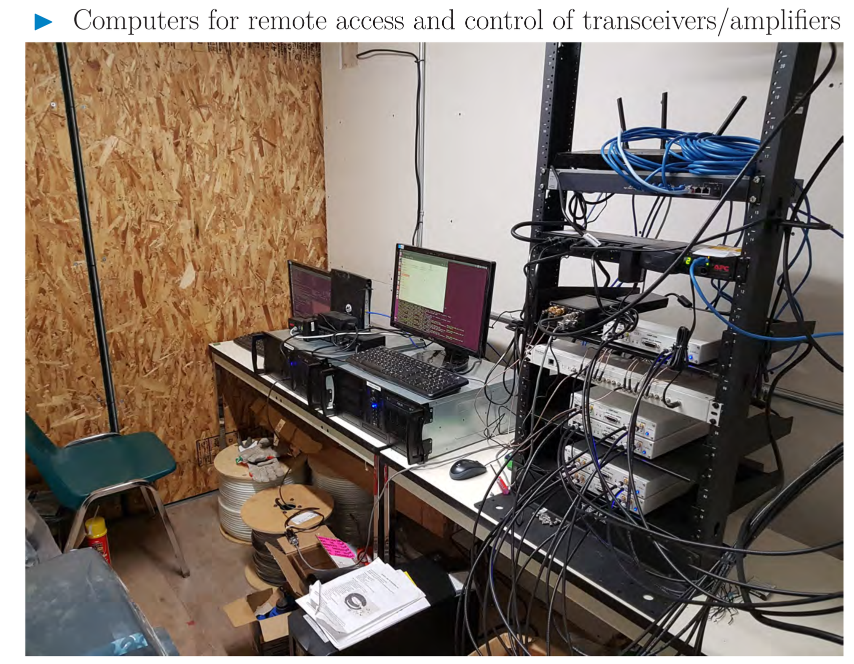


The Transmitter Electronics

- 3 stage, 59 dB gain, 600 W amplifiers
- Temperature/fan/SWR monitoring using a Raspberry Pi
- 120 VAC input from PDU to turn amplifier on/off remotely
- Ethernet connection to Pi for remote monitoring/control

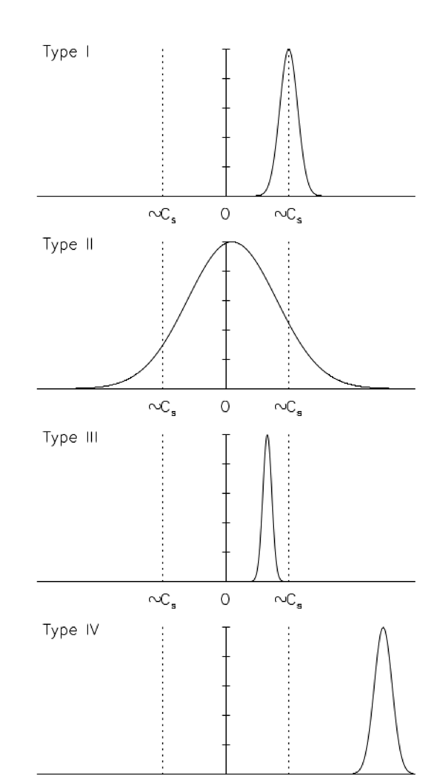


- Similar setup to receiver system
- X300 transceivers on rack connected to 10 Gbps Switch
- Computers for remote access and control of transceivers/amplifiers



E-region Irregularities

- 4 "types" of radar echoes historically observed and defined
- Each type is defined by the spectral width and Doppler shift
- Type I is caused by the Farley-Buneman instability (narrow width and ion-acoustic speed Doppler)
- Type II is thought to be the gradient drift instability (broad width and near zero Doppler)
- Type III/IV are not well understood (both narrow width, type III approximately half ion-acoustic speed, type IV double ion-acoustic speed)

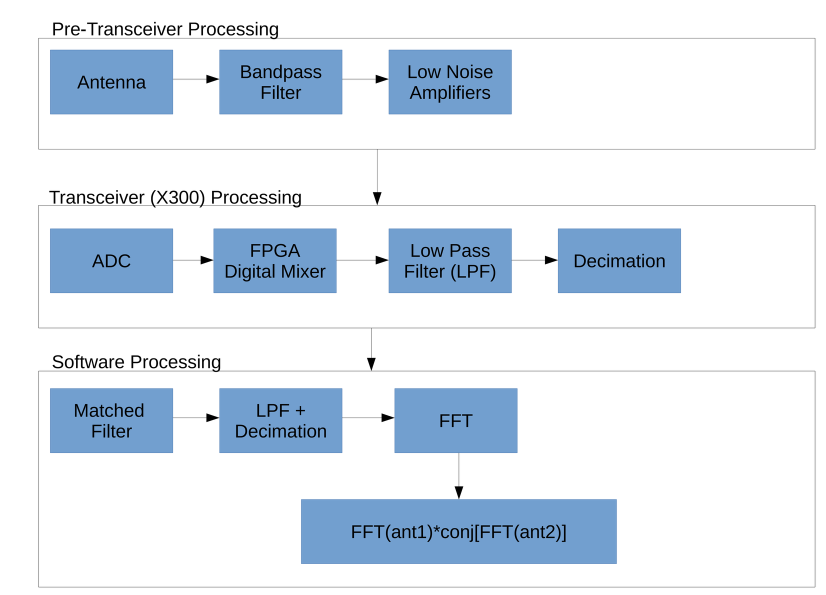


Signal Modulation

- System uses a CW pseudo-random phase coding scheme (pulse compression)
- result → simultaneous high spatial and Doppler resolution
- The phase of the signal changes every 10 microseconds, allowing for 1.5 km range resolution, with the code being 10,000 pulses long (100 milliseconds)

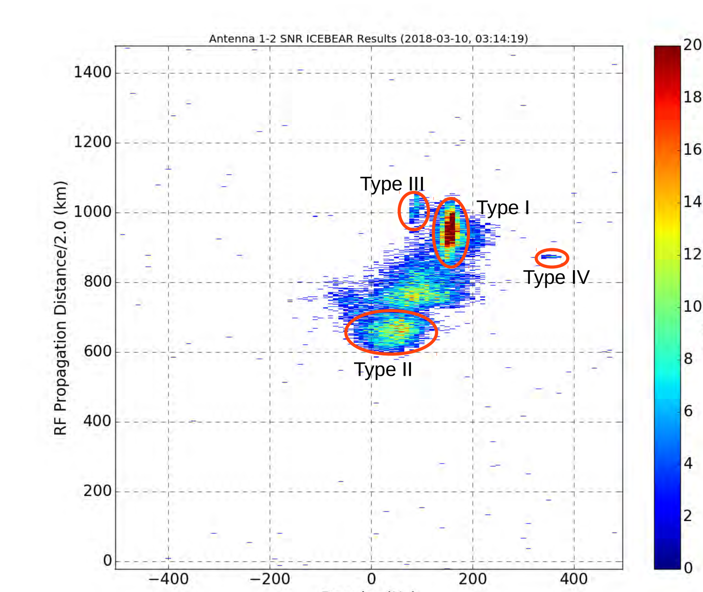
Data Processing (Receiver)

- Pre-Transceiver Block: uses hardware to filter the signal and amplify it into the dynamic range of the receiver
- Transceiver Block: converts the analog signal to a digital one, digitally mixes the signal to baseband, filters it and records it
- Software Block: multiplies the recorded raw complex voltage samples and the complex conjugate of the code transmitted to "un-wrap" the phase (matched filtering), then filters, decimates, and takes FFT for determination of power and phase

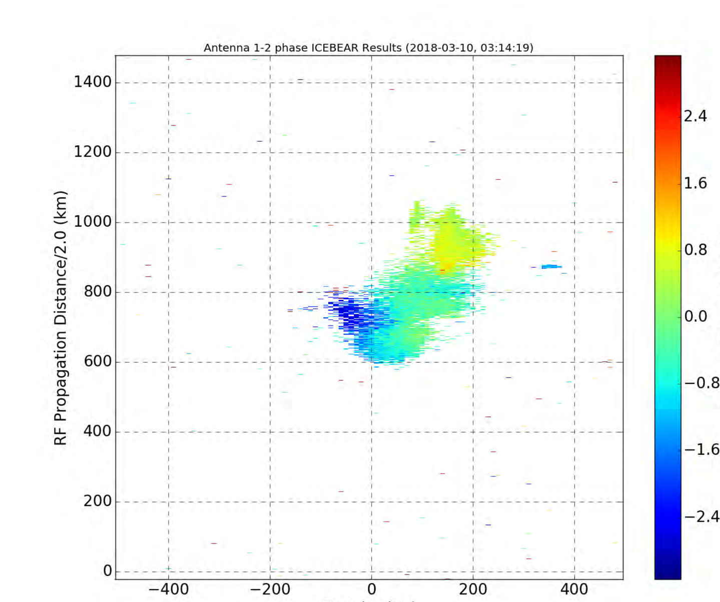


ICEBEAR Results

- ICEBEAR has observed all 4 types of echoes at the same time
- Doppler frequency multiplied by 3 gives approximate speed (m/s)
- ICEBEAR SNR on March 10, 2018

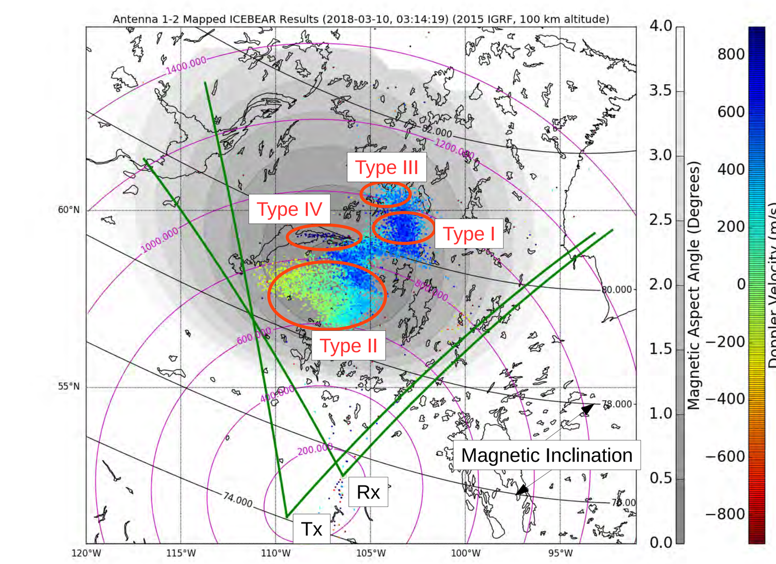


- ICEBEAR Phase Difference on March 10, 2018

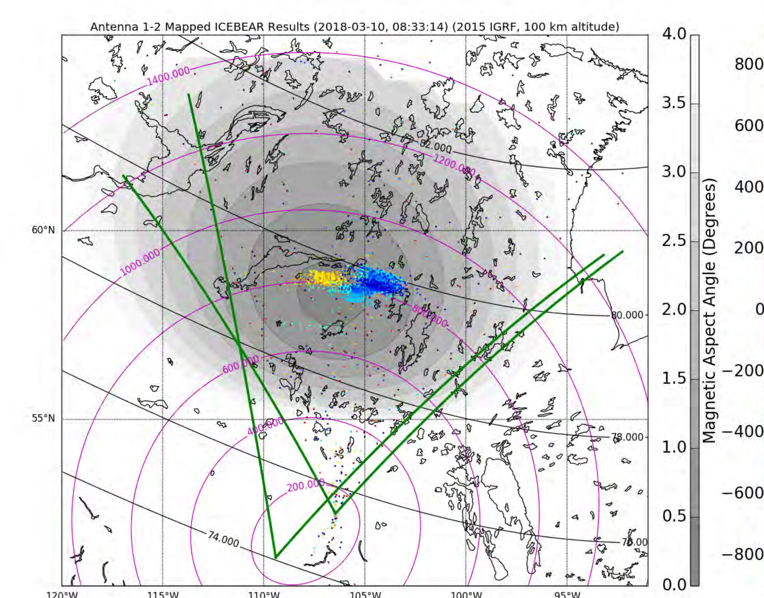


Mapping the ICEBEAR Results

- The range and azimuth (phase) can be used to plot the scatter on a map
- Velocity map plot of echoes with a SNR > 2.0 from the previous plots (aspect angle in grey scale contour)



- Example of ionospheric flows in close proximity moving in opposite directions



Summary and Conclusions

- A new bistatic ionospheric E-region radar named ICEBEAR is now operational and is providing new and exciting results
- Simultaneous high temporal and spatial resolution using a CW phase-modulated signal allows for greater insight into E-region dynamics
- Due to digital design, ICEBEAR is highly adaptable and configurable, only requiring software changes for new pulse modulation schemes
- All 4 E-region irregularity types have been observed, as well as meteor trails
- Results can be mapped to geographic coordinates, allowing for multi-instrument studies of common volumes
- With the high temporal resolution capabilities of ICEBEAR, Magnetosphere-Ionosphere coupling can be investigated with an emphasis on Alfvén wave detection
- Future work includes construction of an interferometer for elevation determination (3D mapping)

Acknowledgements

The authors gratefully acknowledge funding support from the Canadian Foundation for Innovation (CFI) along with the Government of Saskatchewan and the Natural Sciences and Engineering Research Council (NSERC) of Canada for the development and operation of the new 50-MHz VHF Digital Bistatic E-region ICEBEAR radar, including graduate student support.

CSA ASC NSERC CRSNG INNOVATION.CA Canada Foundation for Innovation | Fondation canadienne pour l'innovation