First radar measurements of ionospheric irregularities by the Radio Aurora Explorer CubeSat

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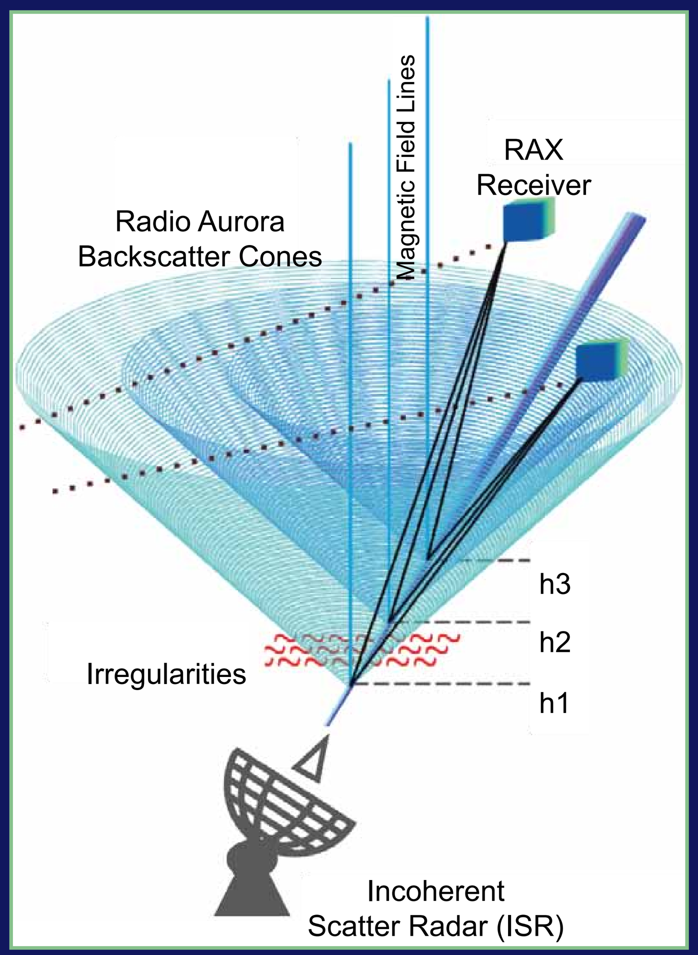
Abstract

On 8 March 2012, the NSF-selected Radio Auroral Explorer (RAX) mission detected first-ever coherent UHF echoes from auroral turbulence using a CubeSat bistatic space-based radar. The RAX radar receiver acquired these echo signals during an early morning overflight of the Poker Flat Incoherent Scatter Radar (PFISR) during highly disturbed (> 550 nT) geomagnetic storm conditions. Ionospheric state variables were favorable for growth of Farley-Buneman waves with significant *E*-region densities ($N_e \sim 10^{11}$ m^{-3}) and observed ion drifts nearly three times the local ion acoustic velocity. An auto-correlation analysis recovered the distribution of E-region backscatter at 3-km vertical and arcminute magnetic aspect angle resolution - a granularity unprecedented for auroral zone coherent scatter radar measurements. The measured Doppler of the backscatter shows the saturation speed of the meter-scale plasma waves and evidence for altitude-dependent modulation of the ion acoustic velocity. Data analysis of raw complex voltage is underway with a goal to reveal fine aspect angle structure of auroral turbulence.

Background

- RAX is a space weather mission to characterize formation of one important class of disruptive ionospheric structures: high-latitude field aligned irregularities (FAIs).
- RAX, a bistatic ground-to-space radar, uses NSF ground-based radars (Alaska, Canada) as a megawatt source of RF pulses.



- RAX-2 space-based magnetic field geometry enables FAIs to be resolved at high spatial scales and at k-vector values inaccessible to ground-based radars.
- Use of direct ISR measurements (plasma temperature, ion drift velocity) allows assess ment of ionospheric predisposition of onset of FAI-related turbulence.
- Launched into 400 X 820 km elliptical orbit on 28 October 2011, RAX-2 executed nearly 20 experiments in quiet geomagnetic conditions no FAI detection by 8 March 2012.

FIGURE 1: RAX bi-static measurement scenario uses megawatt-class ground-based incoherent scatter radar (ISR) transmitters to illuminate naturally occuring auroral turbulence. Bragg-scattered coherent echoes then propagate along the cone-shaped surfaces and are rapidly sampled and time-stamped by the CubeSat radar receiver. Megahertz sampling at orbital velocities yields sub-meter-scale spatial and arcsecond angular resolution for these irregularities. The ISRs also provide contextual measurements of plasma density, temperature, and drift so as to gauge ionospheric susceptibility to irregularity formation.

Experiment

- Poker Flat Incoherent Scatter Radar (PFISR) commanded to transmit 100-microsecond uncoded pulses at 10-ms period on the 449-MHz RAX-2 frequency.
- Experimental geometry at 811 km altitude indicates a large range of perpendicularity (Figure 2) during the 300-s experimental window.
- 1.2 GB of complex (I & Q) voltages acquired on-board were converted to SNR units and rendered into a 50-kB range-time-intensity plot (Figure 3).
- After SNR plot downlink, raw I & Q voltages at 1-MHz sampling rate have been downlinked for follow-on Doppler analysis.
- Doppler analysis uses direct beam ISR signal and known orbital trajectory to estimate projected Doppler shift for the coherent-scatter raypath.

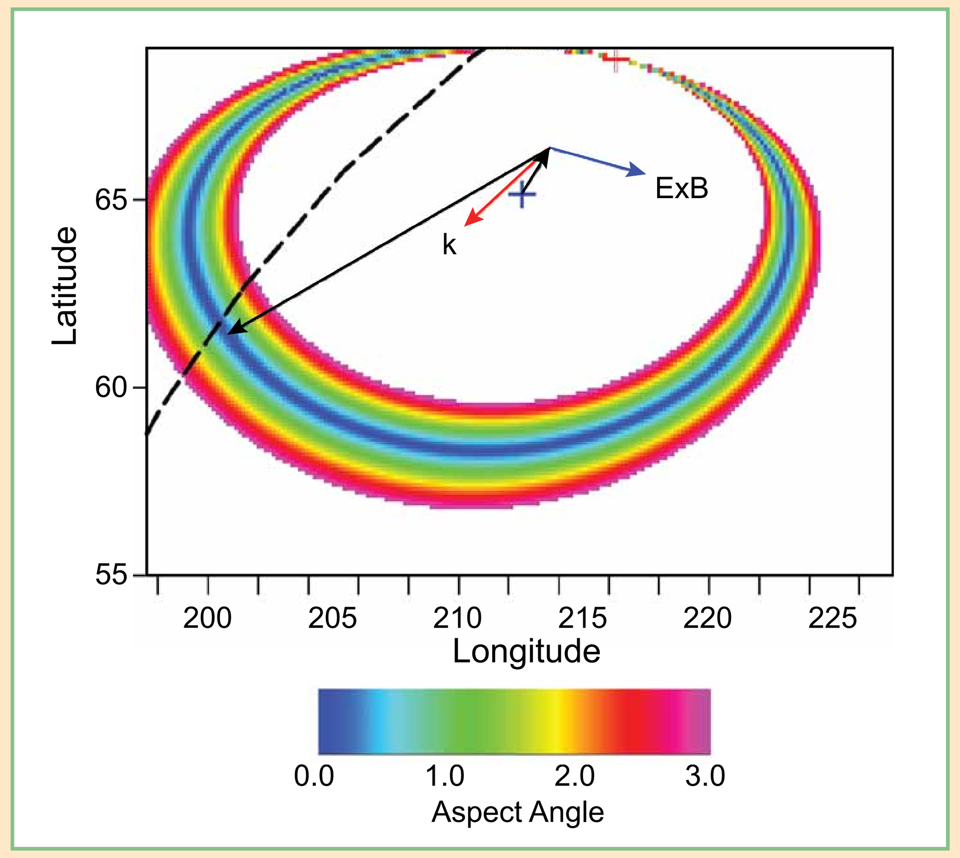


FIGURE 2: Experimental geometry showing color-coded magnetic aspect angle for the 800-km RAX overflight of PFISR (denoted by blue cross) on 8 March 2012. The spacecraft trajectory is shown as a dashed line, the incoming and backscattered radar pulses are shown as a thin black line, the scattering Bragg wave vector and the plasma drift (ExB) velocity are shown as red and blue arrows, respectively.

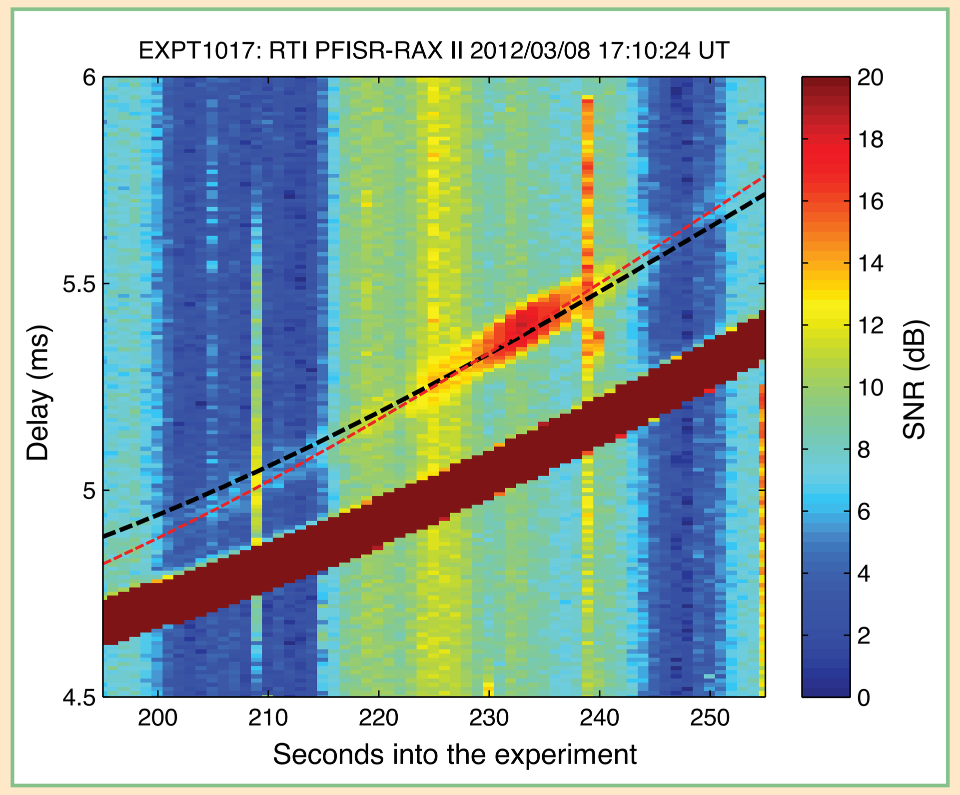


FIGURE 3: Range-time-intensity plot for the duration of E-region echoes observed by RAX. The black line marks the arrival time of echoes from the altitude of 100 km. The red line is a low-order polynomial range/time fit to the trace of the echo peak.

Observations

- Poker Flat horizontal magnetic deflection was indicative of storm conditions (~ 550 nT).
- A strong ionospheric electric field was measured with PFISR (~ 75 mV/m).
- The RAX range-time-intensity plot (Figure 3) indicated a 50-second period during which enhanced echo power coincided with exact geomagnetic field perpendicularity.
- FAI echoes, delayed 330 microseconds relative to the direct PFISR beam, indicated an E region scattering altitude (~ 100 km).
- SNR measured along a low-order polynomial fit to the echo morphology indicates that peak SNR occurred at a 90° geomagnetic aspect angle and at an altitude of 102 km (Figure 4).

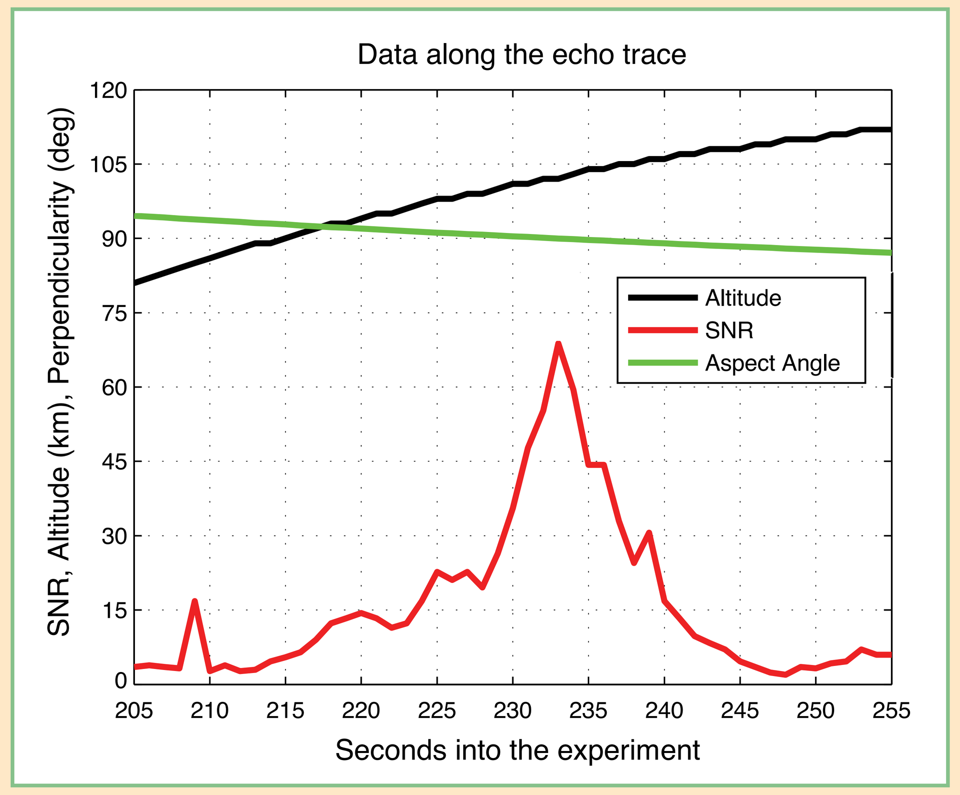


Figure 4: SNR (red), aspect angle (green), and backscatter altitude (black) for the 8 March 2012 echo event as measured along the low-order polynomial (red range/time trace shown in Figure 3). Note that SNR peak is observed at the exact point of aspect angle perpendicularity.

Discussion

- Auroral electrojet Farley-Buneman waves are favorably excited when the ion drift velocity (V_i) exceeds the local ion acoustic speed:

$$C_s = \sqrt{K_B(\gamma_e T_e + \gamma_i T_i)/m_i}$$

  where K_B is Boltzmann's constant; γ's are altitude dependent ratio of specific heats; T_e is electron temperature; T_i is ion temperature; and m_i is ion mass.
- For 8 March 2012,

  $V_i = 1500$ m/s $>$ $C_s = 500$ m/s

  and thus we expected to observe Farley-Buneman turbulence.
- Comparison of the echo Doppler velocity (blue trace, Figure 5) at 300 – 400 m/s with the Bragg-vector-projected ion drift velocity (dashed black line, Figure 5) at 600 m/s suggests a saturation of turbulent phase speeds at 400 m/s.
- A trend of increased Doppler velocity with increasing altitude implies an increase in ion acoustic velocity due to enhanced T_e.

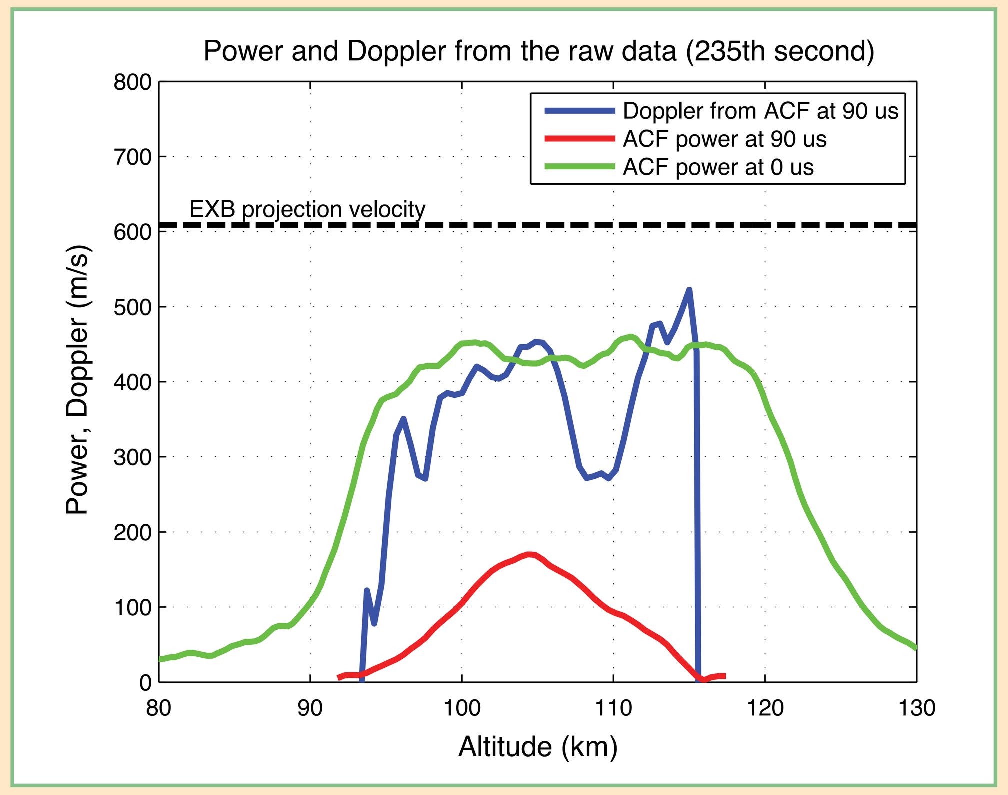
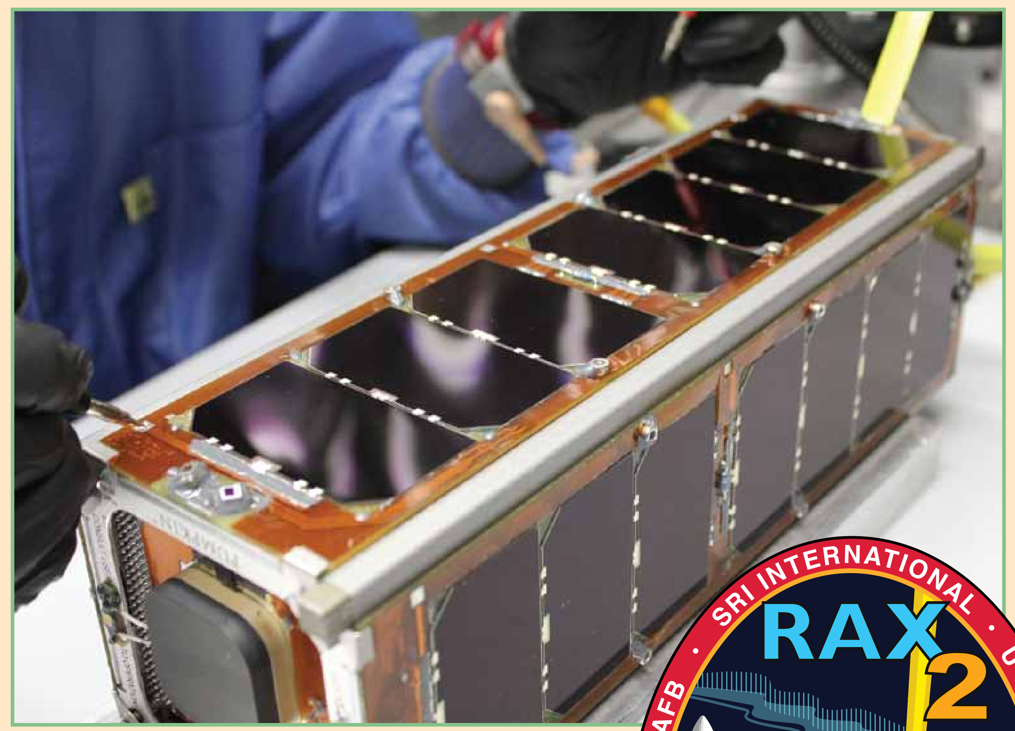


Figure 5: Raw echo intensity (green), altitude-resolved intensity (red) and Doppler velocity (blue) as a function of altitude at the time of peak echo SNR (Figure 3 at 235 seconds into experiment).

Conclusions

- Following an extended period of geomagnetic quiescence, the NSF RAX-2 mission has, for the first time, measured UHF auroral backscatter most likely due to fully saturated Farley Buneman turbulence.
- An additional storm event (25 April 2012) has generated similar echo signatures.
- Work on characterizing the aspect angle sensitivity of meter-scale waves at the highest angular resolution is underway for both events.



Acknowledgements

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