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HIGH RESOLUTION AURORAL CLUTTER MAPPING USING THE VERONA AVA LINEAR ARRAY RADAR

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Abstract - The Verona Ava Linear Array Radar (VALAR) is a high resolution experimental HF backscatter data acquisition system designed to investigate the characteristics of high latitude auroral clutter. The transmit system located in Ava, New York, is capable of providing RF signals in the 2-30 MHz band with up to 300 kW average power. The receive system at Verona, New York, consists of a 72 element linear antenna array (extending 700 meters in length) and 36 identical HF receivers. Since the completion of system test and calibration at the end of 1989, data acquisition campaigns have been carried out on a near monthly basis. In this paper we provide a brief description of VALAR and present some examples of initial results from the preliminary analysis of HF auroral backscatter data acquired during 1990. These examples demonstrate the capability of VALAR as a high resolution HF backscatter data acquisition system.

1. INTRODUCTION

Over-the-horizon backscatter (OTH-B) radar systems operating at high latitudes are subject to periods of degradation in performance due to the presence of electron density irregularities in the auroral ionosphere. OTH-B radar systems utilize oblique reflection of HF waves from the ionosphere to propagate a signal to the ground beyond the line of sight of the transmitter. The backscattered signal from the ground is returned to the receive array, in general located near the transmitter, by a second oblique reflection from the ionosphere. The signal propagating in the auroral ionosphere can be backscattered directly to the receive array when the wave normal of the HF signal is perpendicular (or al-



most perpendicular) to the magnetic field-aligned irregularities¹. This unwanted backscattered radar signal is termed auroral clutter, and is one of the identified sources of residual clutter encountered by OTH-B radars operating at high latitudes. Residual clutter is characterized by an increase in the effective noise level above the external noise when the transmitter is turned on. It also tends to spread the Doppler frequency beyond the normal ground backscatter Doppler limits of ± 1 Hz. Many important properties of auroral clutter remain unidentified and are poorly understood, requiring extensive analysis and characterization prior to the development and evaluation of clutter mitigating techniques.

The Verona Ava Linear Array Radar (VALAR) is a unique experimental HF backscatter radar system dedicated to investigating the characteristics of auroral backscatter. The system is currently operating in a data acquisition mode to collect HF propagation data. The elemental data collected are then processed and analyzed at Rome Laboratory, Hanscom AFB. In this paper we provide a brief description of VALAR and present some initial results from the analysis of data collected during 1990.

2. SYSTEM DESCRIPTION

VALAR was developed by Rome Laboratory to establish a dedicated experimental HF backscatter data acquisition system to resolve various residual clutter and clutter mitigating issues. Currently, the system is configured to acquire HF auroral backscatter data to investigate the characteristics of auroral clutter. The transmit system is located at the Rome Laboratory HF transmit site in Ava, New York, and the receive system is at the Verona Test Annex in Verona, New York, 30 km from the transmitter. The approximate geographical location of VALAR is $43^{\circ} 24'$ North and $75^{\circ} 23'$ West. From this location, geographic north is within 5° of geomagnetic north.

2.1. Transmit system

The transmit system at Ava features various transmitter and antenna configurations for both low and high power requirements. The facility is capable of supplying RF waves in the 2-30 MHz band with up to 300 kW average power. It has the capability to simultaneously transmit a wideband Swept-Frequency Continuous Wave (SFCW) and a narrowband linear Frequency-Modulated Continuous Wave (FMCW) signals. The wideband SFCW signal is required to operate the sounder located in Verona to obtain wideband oblique backscatter ionograms. During the data acquisition phase, a slanted rhombic antenna was used in conjunction with a Continental transmitter to support the high transmit power requirement of VALAR. At 10 MHz, the theoretical 3 dB elevation beamwidth is 14° centered at 10° elevation. The theoretical 3 dB azimuthal beamwidth is also 14° .

2.2. Receive system

2.2.1. Antenna array

The receive system at Verona Test Annex includes a 700 meter linear array. The configuration of the linear array is shown in figure 1. It consists of 36 sub-arrays, each with two active and two passive monopoles. The boresight of the array is 10° east of true north. The array was designed to optimize the performance over the frequency band of 6 to 12 MHz because auroral clutter is primarily a nighttime phenomena and the ionosphere does not support higher frequencies during these times. Antenna pattern measurements at 12 MHz have shown 2.5° 3 dB beamwidth, 23 dB array gain, and 30 dB RMS sidelobe levels². Measurements have also shown that an azimuthal coverage of -30° to $+30^\circ$ (with respect to the boresight of the array) is possible at 12 MHz. The coverage area of VALAR, superimposed on a map of North America, is shown in figure 2. Also depicted in figure 2 is the approximate position of the auroral oval at 21:00 EST during an average magnetic index of

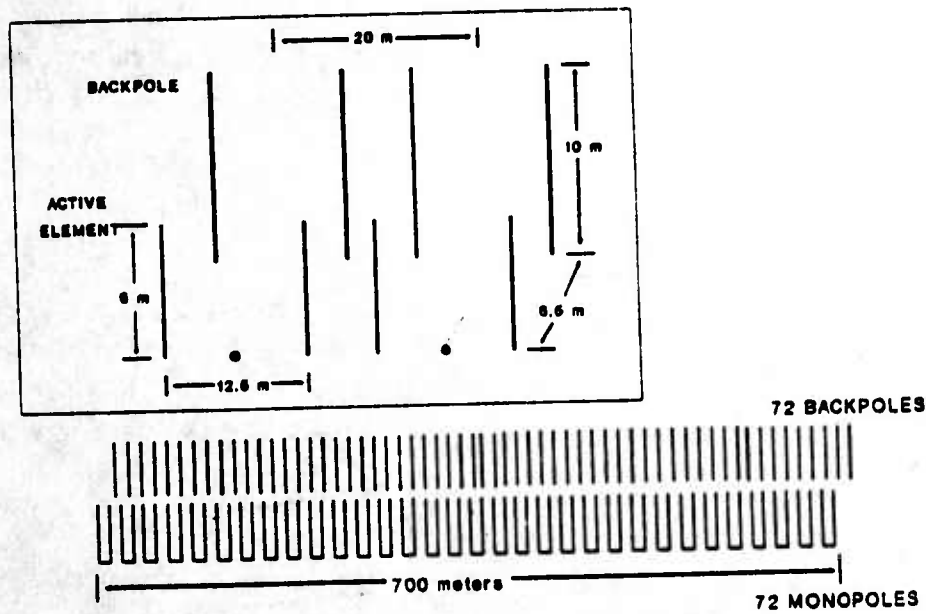


Figure 1. Configuration of VALAR receive antenna array showing the linear array and subarray geometry

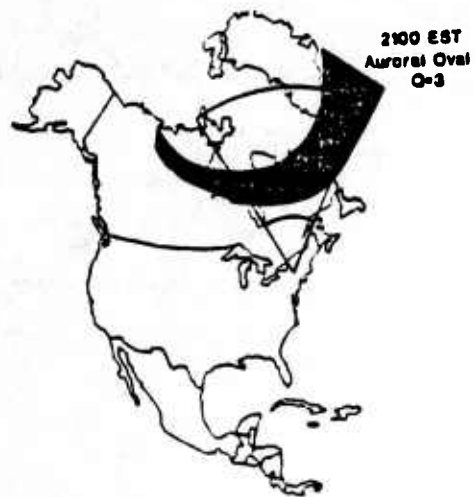


Figure 2. Coverage area of VALAR. Also shown is the approximate position of the auroral oval at 21:00 EST with magnetic index $Q=3$.

Q=3. Note that both equatorward and polarward boundary of the auroral oval is within the field of view of VALAR. Thus VALAR is ideal system to observe and characterize HF backscatter from the auroral ionosphere.

2.2.2. Receive electronics

The basic block diagram of the system is shown in figure 3. It consists of 36 identical subsystems, a MicroVaxII, and a Kennedy tape recording device. Each subsystem, in addition to the subarray discussed above, also includes a preamplifier and an HF receiver. The receiver converts the HF signal at the output of the preamplifier to complex digital baseband data. The digitized data are temporarily buffered in the RAM of each receiver, then serially transferred

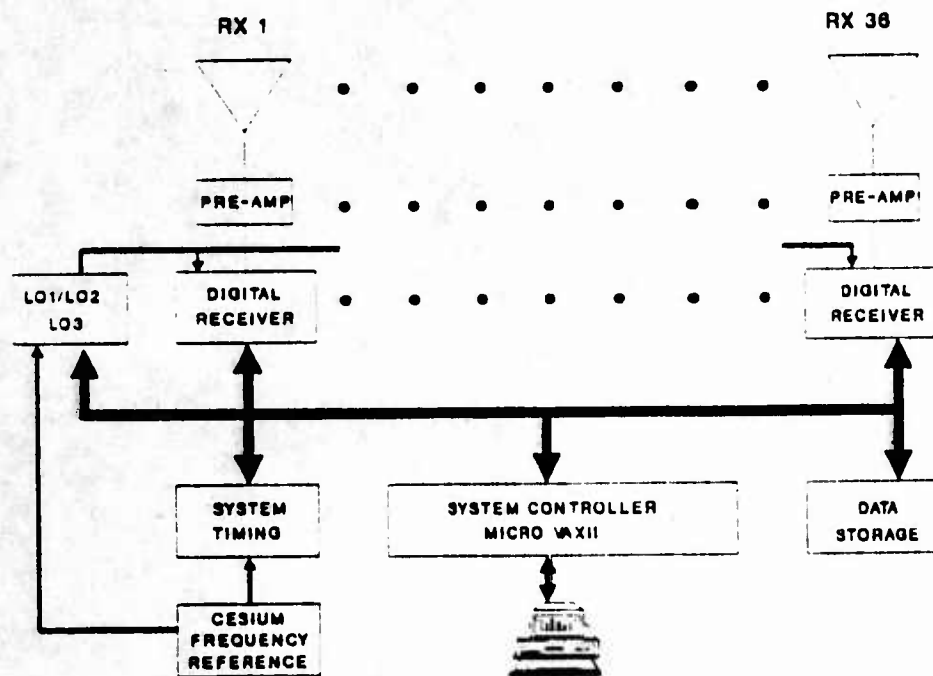


Figure 3. VALAR receive system block diagram

to the Kennedy tape drive and recorded on a tape. The MicroVaxII is the system controller for all data acquisition commands and transfers. The data acquisition software on the MicroVaxII allows the user to select various system parameters during the data acquisition phase. Typical values of system parameters are shown in table 1.

Transmit Power	100 kW (RMS)
Waveform	Linear FMCW
Sweep Rate	250 kHz/s
Waveform Repetition Frequency (WRF)	25 Hz
Sweep Bandwidth	10 kHz
Baseband Bandwidth	+/- 5 kHz
Sampling Rate	10 kHz
Coherent Integration Time (CIT)	3.2 seconds

Table 1. Typical system parameters used during data acquisition

2.2.3. Diagnostic software

In addition to the data acquisition software, a diagnostic software is also available on-site. This software enables a quick check of the system performance and the quality of the data being recorded. The operator can simultaneously display the amplitude, phase, and signal-to-noise ratio (SNR) of all 36 channels, examine the frequency spectrum of a single channel, and plot azimuth distribution of power incident on the aperture for a given range. Further data processing is accomplished at Rome Laboratory, Hanscom AFB, Massachusetts.

3. INITIAL RESULTS

On September 24 1990, HF propagation data were collected during the period of 20:00 to 23:00 eastern standard time (EST). A waveform repetition frequency (WRF) of 25 Hz was selected to eliminate possible range ambiguity. The average transmit power was 100 kW and the operating frequency was 10.58 MHz for the data presented in this section.

3.1. Oblique backscatter ionograms

The wideband oblique backscatter ionograms of figure 4 present a good comparison of ground backscatter echoes with the direct scatter echoes from field-aligned irregularities. Figure 4a, obtained at 20:30 EST, is typical ionogram showing 2F ground backscatter during undisturbed ionospheric conditions.

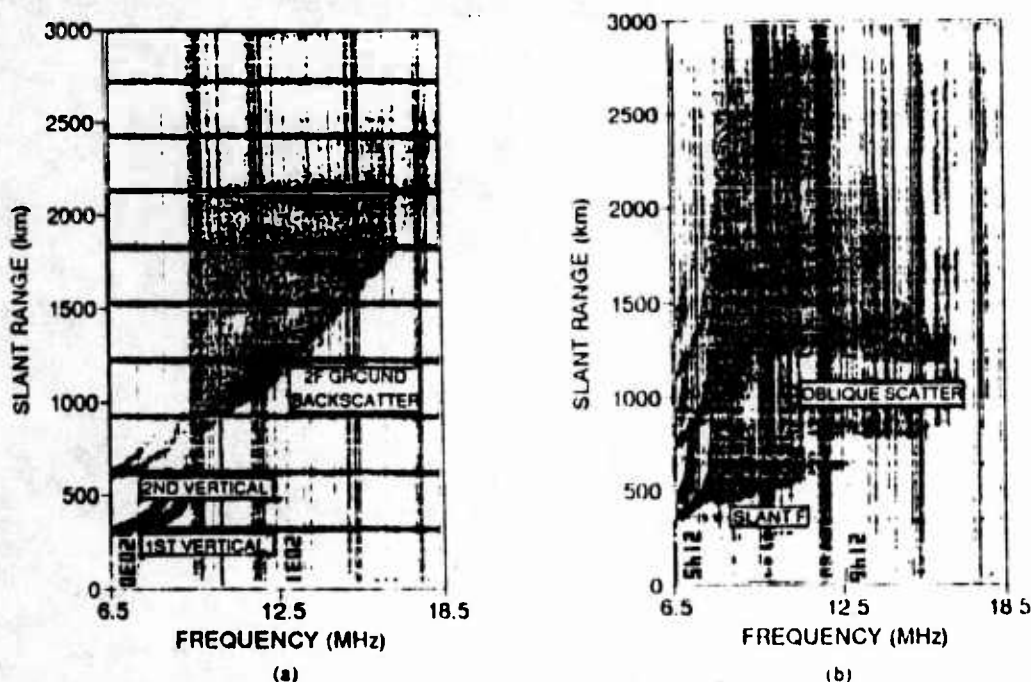


Figure 4. Oblique backscatter ionograms obtained during September 24 1990 at (a) 20:30 and (b) 21:40 EST

The '2F' indicates a signal that is obliquely reflected from the F-region ionosphere, backscattered from the ground, and obliquely reflected a second time to the receive array. As indicated on the ionogram, the main features are the first vertical incidence, the second vertical incidence, and the 2F ground backscatter. The first vertical incidence is a signal that propagates vertically, reflects from the ionosphere, and returns to the receiver. The second vertical incidence refers to a signal that travels the ray path of the first vertical incidence twice. Note that the 2F ground backscatter begins from the second vertical incidence and linearly increases in slant range with increasing frequency. This is because, in general, an obliquely transmitted signal requires two reflections from the ionosphere to return to the receiver. As the transmit frequency increases, the oblique angle of reflection increases, thereby increasing the slant range of the 2F ground backscatter region.

In comparison to figure 4a, the ionogram obtained at 21:40 EST (figure 4b) shows additional backscattered signals. These additional backscattered signals are identified as slant-F and oblique scatter. The slant-F and oblique scatter are two of the three identified types of HF auroral clutter at high latitudes³. Slant-F echoes are the direct backscattered signals from field-aligned irregularities in the F-region ionosphere. From the location of VALAR, it is normally associated with irregularities in the sub-auroral F layer. The oblique scatter is typically associated with echoes from auroral F region and may exhibit both long and short slant ranges. The long slant range is associated with high elevation angle while the short slant range implies low elevation angle⁴. The third type, echoes from auroral E-region, is not observed by VALAR, except under disturbed magnetic conditions.

3.2. *Characteristics of 2F Ground Backscatter*

Figure 5 shows the amplitude-range-azimuth (ARA) map of backscatter energy at 20:30 EST. The leading edge of the 2F ground backscatter occurs at 900 km, and this is in agreement with the oblique ionogram shown in figure 4a. The ground backscatter is observed at all azimuths, and is the dominant

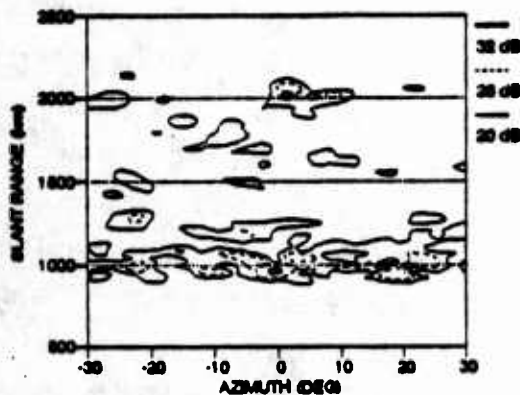


Figure 5. Amplitude-range-azimuth (ARA) map of the backscatter energy observed at 20:30 EST. Three contour levels of constant amplitudes are shown for slant range and azimuth.

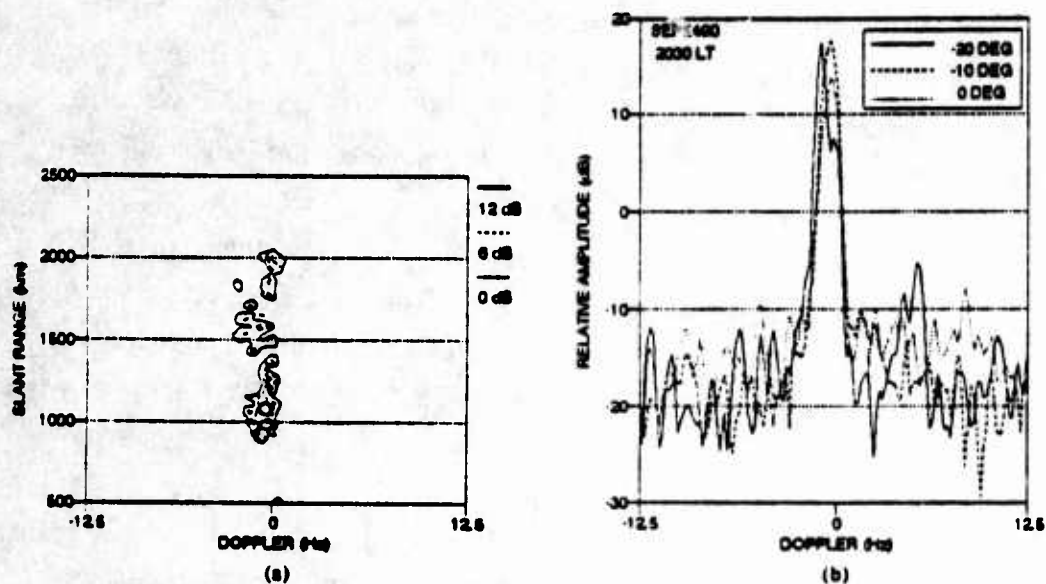


Figure 6. (a) Amplitude-range-Doppler (ARD) map of the backscatter signal at 20:30 EST for -10° (true north) beam, and (b) the mean Doppler spectrum of 2F ground backscatter for various azimuth beams.

backscatter in the figure. The Doppler characteristics of 2F ground backscatter can be examined for various azimuth angles. Figure 6a is the associated amplitude-range-Doppler (ARD) map with the beam steered at -10° (true north). The strongest signals are returned from a slant range of 900 to 1200 km. The spread in Doppler is very small, indicating a fairly undisturbed ionosphere. Figure 6b shows the mean Doppler spectrum (averaged over slant range from 900 km to 1000 km) for various azimuth beams. The 2F ground backscatter is shown to be about 30 dB above the mean clutter/noise level and the spread in Doppler is confined to ± 1 Hz about 0 Hz.

3.3. Characteristics of auroral clutter

3.3.1 Range-azimuth distribution of auroral backscatter

The ARA map of backscattered energy at 21:40 EST is shown in figure 7. There are three principle features: (1) the slant-F echoes at 550 km are confined in azimuth, (2) the oblique scatter at 800 km is relatively weak in amplitude, and (3) the oblique scatterers beyond 1200 km are of different scale sizes and locations. Upon initial observation, three independent echoes from auroral F-region are identifiable between 1200 and 1500 km (other irregularity patches of different sizes and locations were also observed at later times). The 2F ground backscatter, expected around 1400 km when examining the ionogram in figure 4b, is not identifiable because the auroral F-region echoes dominate at this slant range. The oblique scatter at 800 km corresponds to low elevation angle ray. Since the array elements are vertical monopoles with very poor low elevation coverage, the weak relative amplitude observed is expected.

3.3.2. Doppler characteristics of auroral backscatter

ARD maps for 21:40 EST are shown in figure 8. The azimuth beams were steered to -20° , -10° , and 0° , respectively. The main features of these figures are: (1) the slant-F echoes at 550 km exhibits shift in peak Doppler frequency as

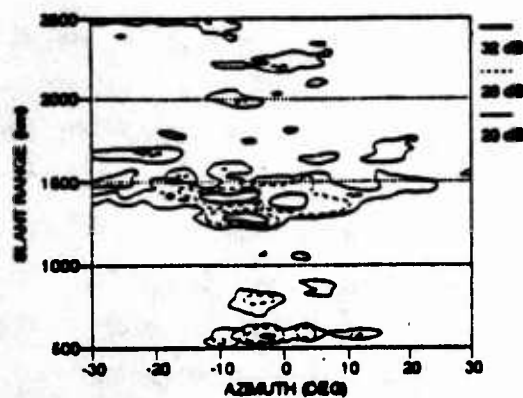


Figure 7. ARA map of the backscatter energy at 21:40 EST

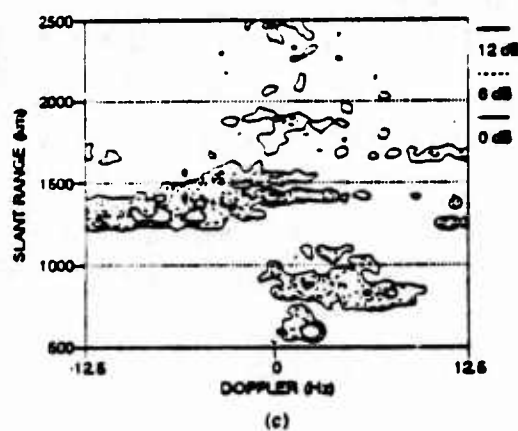
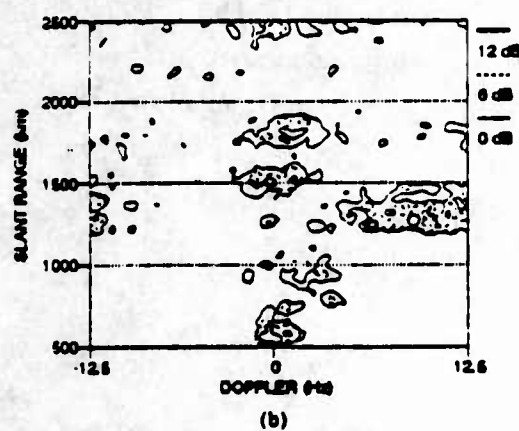
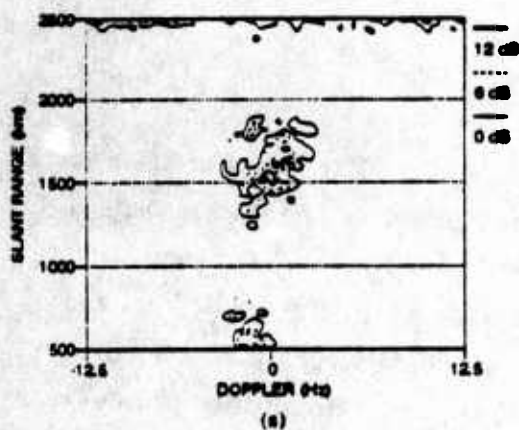


Figure 8. ARD maps at 21:40 EST for various azimuth beams.
(a) -20° , (b) 10° , and (c) 0° .

a function of azimuth angle, (2) the strong echo at 1500 km (figure 8a) shows spread about 0 Hz, and (3) the direct backscatter from auroral F-region at 1200-1400 km (figure 8b and c) exhibits very large shift and spread in Doppler. Note the difference in Doppler characteristics of the auroral clutter at -10° in comparison to the beam at 0° . While the auroral clutter at -10° is characterized by positive Doppler, the Doppler at 0° is predominantly negative. Also identifiable in figure 8c is the low angle oblique scatter at 800 km.

Figure 9 shows the mean Doppler spectrum of slant-F echoes for these three different azimuth beams. The peak Doppler frequency shifts from negative to positive as the beam is steered from west to east of true north. This indicates that the electron density irregularities responsible for the slant-F echoes drift away from the radar at the -20° beam and towards the radar at 0° . The slant-F echoes are also characterized by relatively narrow Doppler spread of 5 Hz, independent of azimuth.

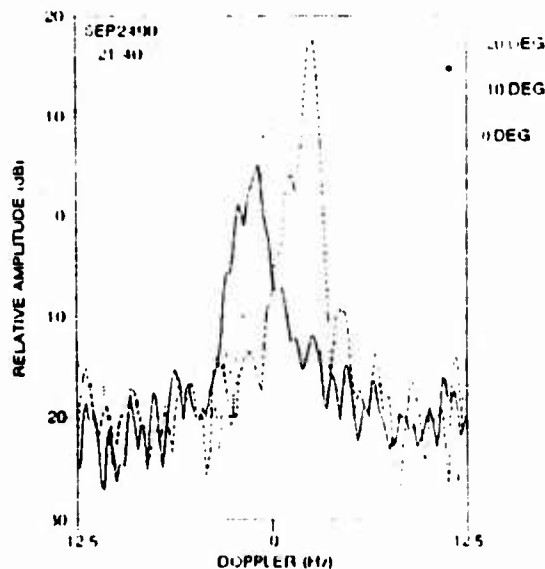


Figure 9. Mean Doppler spectrum of slant-F echoes for -20° (solid line), -10° (dotted line), and 0° (dashed line).

While the slant F echo shows shift in frequency, the strong echo at 1500 km (figure 8a) exhibits relatively small spread in Doppler about 0 Hz. At this angle of incidence (-10° west of true north) the direct backscatter from the auroral F-region should show a wide spread and shift in Doppler due to the motion of the irregularities. Since the general motion of the large-scale auroral irregularities is east to west and this beam is west of the other two, it is possible that the auroral clutter has not affected this azimuth beam as of 21:40 EST. Therefore, we conclude that the signal at 1500 km is the ground backscatter. This signal is also identifiable in figure 8b.

Figure 10 shows the mean Doppler spectrum of ground backscatter at 20:30 and 21:40 EST for the -10° beam. Also shown in figure 10 is the mean Doppler spectrum of external noise (transmitter off). The increase in effective noise level due to clutter is about 10 dB and the spread in Doppler is about ± 5 Hz. Since the origin of this echo is the ground, the source of clutter is most likely at the midpoint of the propagation path. This increase in effective noise

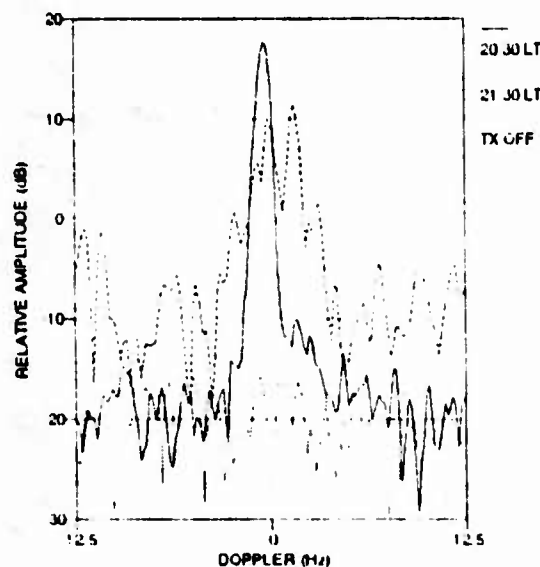


Figure 10. Mean Doppler spectrum of ground backscatter at 20:30 EST (solid line), 21:40 EST (dashed line), and external noise (dotted line) for -10° azimuth beam.

level and the spread in Doppler are probably due to the induced phase and amplitude distortion along the wavefront of the signal as the wave propagates in the ionosphere. This conclusion is true if there were no multi-path modes due to direct backscatter from the auroral F-region in the same range bin. We believe that this is the case since the spread in Doppler is relatively small and it is centered about 0 Hz.

The difference in Doppler characteristics of auroral clutter seen in figure 8b and c can be explained as follows. In order to eliminate range ambiguity, a WRF of 25 Hz was required. This selected value of WRF limits the Doppler bandwidth to -12.5 to 12.5 Hz, and consequently the maximum unambiguous Doppler velocity observable. The maximum unambiguous Doppler velocity for given operating frequency and WRF is 177 m/s. If the Doppler velocity is greater than 177 m/s, an ambiguity results due to Doppler aliasing. All positive Doppler velocity greater than 177 m/s will 'wrap-around' to the opposite band and appear as negative Doppler. Considering the approximate position of the auroral oval and the direction of the electrojet current relative to VALAR at 21:40 EST, the observed Doppler should be positive. Furthermore, the Doppler velocity along the radar look direction for the 0° beam will be greater than the -10° beam. Therefore, we can conclude that the negative Doppler observed for the 0° beam is equivalent to Doppler velocities greater than 177 m/s.

4. SUMMARY AND CONCLUSIONS

Initial results from the VALAR HF backscatter radar system have been presented in this paper. The capability of the VALAR system to observe auroral clutter makes it a useful tool for understanding and mitigating the problems associated with OTH-B radars operating at high latitudes. The development of auroral clutter in the evening has been shown. The slant-F echoes were identified as originating in the sub-auroral zone ionosphere exhibiting less Doppler spread than the oblique scatter echoes and were localized in azimuth. The oblique scatter echoes caused by ionospheric irregularities were shown to be dy-