Clear-Air Backscatter from the Lower Atmosphere Using a High-Power, Millimeter Wave Radar

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***Abstract*— This paper presents our clear-air backscattering observations from the lower atmosphere using the high power, high resolution WARLOC millimeter wave (94 GHz) radar developed at the Naval Research Laboratory (NRL) [1]. With a peak power of 70 kW and a 62-dB gain antenna, the WARLOC radar offers more than 30 dB higher sensitivity than typical weather radars at this frequency. In addition, the radar provides unprecedented high range and spatial resolution with the 50-cm range resolution and a beam width of less than 0.1 degrees, respectively. The radar is currently located at the NRL's Chesapeake Bay Detachment (CBD) facility, on the western shore of the Chesapeake Bay, Maryland, providing observations eastward across the bay. The unique capabilities of the WARLOC radar have opened up new opportunities in atmospheric research. In this paper, characteristics of clear-air backscatter will be presented. Radar cross sections as a function of temperature and height will be discussed. These observations will be related to phenomena such as clear-air turbulence and convective eddies.**

I. Introduction And Background

The WARLOC radar has been regularly detecting low radar cross section echoes from the clear air, even in the winter season when the air temperature is below the freezing point. These echoes have been called "air spikes" due to their similar characteristics to sea spikes from the sea surface scatters. The air spikes appear similar to point targets at the 50-cm resolution. However, coherent structures, which seem to be formed from these air spikes, are also routinely observed. Air spikes are believed to be the radar backscattering returns from the random fluctuations of refractive index caused by atmospheric turbulence.

II. Results

The WARLOC radar has several different waveforms that can be easily switched on-the-fly from one to the other. Two waveforms that are used routinely are a search waveform and an image waveform. The search waveform is a 5μsec pulse with a 14-MHz linear frequency chirp at the center frequency of 94.2 GHz. The return signal is pulse compressed to 100 nsec, producing 15 m range resolution. The image waveform is a 20 μsec pulse with a 300 MHz linear frequency chirp at the center frequency of 94.2 GHz. Using stretch processing, the image waveform produces a 200-m observation window with a 0.5-m range resolution. Due to the 20-μsec pulse width of the image waveform, the minimum range that the 200-m observation window can begin is 3.6 km from the radar.

Using the search waveform, Figure 1 is the amplitude of air spikes as the radar scanning horizontally across the bay taken on June 8, 2007, at 14:47:22 EST. The weather at the radar site was hot and humid with temperature and dew point at 30°C and 22°C, respectively. The radar was scanning in azimuth from 55 to 105 degree at a scan rate of 0.2 deg/sec, and the elevation was held fixed at 2 degree. Individual air spikes were detected rather uniformly over the bay up to a range of 2.2 km. At farther range, well organized coherent structures were observed. Upon close-up observation, this scan shows many "doughnut" or "horse shoe" shape returns. These appears to be the convective cells that rose from the sea surface, bringing the low-momentum fluid into the regions of higher wind speed and creating a region of random isotropic turbulence. When these isotropic turbulences are subjected to a high enough shear, coherent structures are formed spontaneously.

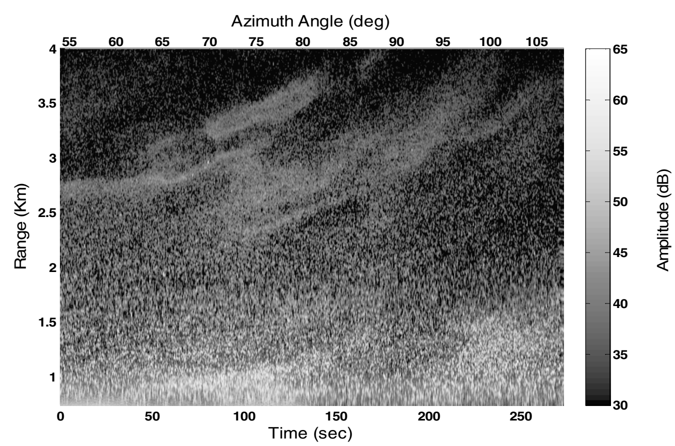

Figure 1: Horizontal scan across the bay, illustrating individual air spikes at close range, and coherent structures above 2.2 km in range.

Figure 2 shows the amplitude of air spikes as the radar scanning vertically using the image waveform taken on June 17, 2007, at 14:41:17 EST. The image was taken at a range of 3.6 km from the radar and antenna scanning vertically at a rate of 0.2 deg/sec. At a 0.5-m range resolution individual backscatter can be easily resolved. A layer at a height of zero meter corresponds to the returns from the water surface of the Chesapeake Bay. As can be seen from this figure, the density of air spikes is higher at low altitudes and becomes sparser at higher elevation. This is a typical density vs. height behavior of air spikes, even with different weather conditions. Using the image waveform, statistical analysis can be performed. Figure 3 shows the histogram distribution of the radar cross section (RCS), with a median RCS of - 67 dBsm. A few outliers at high RCS may be due to insects or birds.

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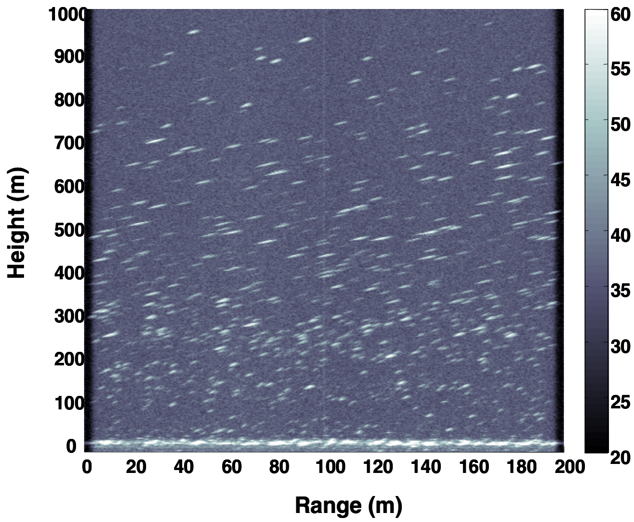

Figure 2. High resolution image of air spikes

Median air spike RCS was calculated for data collected under different weather conditions. Figure 4 shows the median air-spike cross section as a function of air temperature. As can be seen, median air spike cross sections range from -76 dBsm in the winter time, when air temperature dropped well below 5^{o}C, to -64 dBsm when the temperature increased to 25^{o}C in the summer time. Although not shown, air spike cross sections as small as 10^{-10}m^{2} have been observed in the cold weather. The fact that these air spikes have been observed in the cold weather, when temperature at nightfall dropped below -10^{o}C, and the surface of the Chesapeake Bay was covered with ice, strongly rules out insects as the source for these returns. In addition, the strong temperature dependence of the cross sections of these air spikes suggests that the observed returns may be caused by some kind of atmospheric phenomenon, such as clear-air turbulence, or turbulent bursts [2].

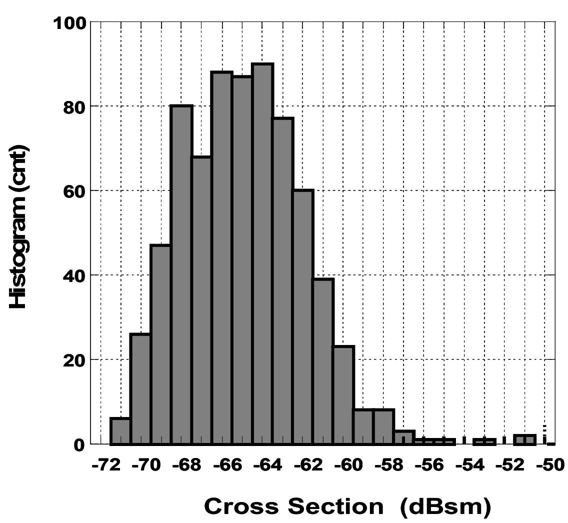

Figure 3. Histogram distribution of air spike cross section

III. Conclusions

With the high resolution and high power provided from WARLOC radar, a new atmospheric phenomenon has been observed. From the data collected thus far, especially the cold weather data, it is concluded that insects are not the only sources of air spikes. Other atmospheric-related phenomena must be responsible for these air spikes, such as non-homogeneities in refractive index caused by turbulence in the atmosphere [3] or turbulent bursts generated in high shear region [4]. The observed clear air backscatter at 94 GHz appear to be formed due to strong shear layers at the outer edges of the ejected plumes that rise from the water surface, bringing the low-momentum fluid into the regions of higher wind speed and creating a region of random isotropic turbulence. They have an intermittent characteristic and are likely to be regions of local high dissipation. The intermittency and high dissipation associated with theses structures make them candidates for regions where the atmosphere may give rise to anomalous radar returns [5].

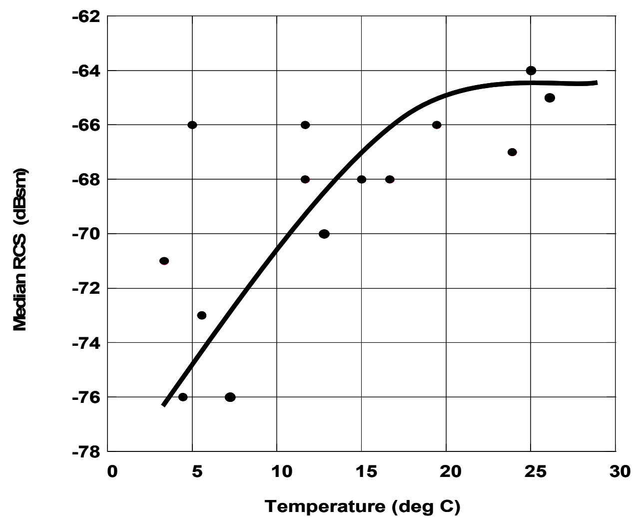

Figure 4. Median RCS Vs. Temperature

Reference

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[4] M. J. Lee, J. Kim, and P. Moin, “*Structure of Turbulence at High Shear Rate*,” J. Fluid Mech., Vol. 216, pp. 561-583, 1990.

[5] Private communication with Dr. Robert Handler at the Remote Sensing Division at NRL.

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