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A NEW DATA ACQUISITION SYSTEM FOR THE U.S. ARMY FM-CW RADAR: STILL A GREAT WAY TO SEE HALF-METER RESOLUTION

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1. INTRODUCTION

The U.S. Army has been operating a high-resolution turbulence profiling radar for many years. This frequency-modulated continuous-wave (FM-CW) radar, which has been used in various atmospheric research studies, currently resides at Dugway Proving Ground, Utah. Although the FM-CW has a steerable antenna mount, it is normally operated vertically to profile clear-air turbulence or hydrometeors. Its spatial resolution is selectable from 0.5 to 10 meters, depending on the maximum height selected. The maximum height depends on signal strength, but is usually set to 4 km for clear-air backscatter resulting in 1024 range cells with a 4-meter resolution. The temporal averaging interval is also user selectable, but is usually set to 3-5 seconds.

Figure 1 U.S. Army FM-CW Radar

The FM-CW radar's data system recently was completely refurbished to use modern PC architecture, software, data acquisition boards, and communications. The previous data system was comprised of an HP-1000 computer, a 9-track tape, several large external 20 MB disk drives, a custom timing board, and an Analogic 16-bit analog-to-digital converter (ADC) and parallel-processing array processor. The new data system utilizes a PC and one internal multifunction 16-bit ADC.

In this paper, the new data system will be described and new data presented. The FM-CW is quite sensitive, and its high spatial and temporal resolution allows the identification of thin turbulence layers, hydrometeors, and point targets such as insects and birds. With the new data system, the FM- CW radar should have many years of continued use in support of both the U.S. Army and other researchers in the atmospheric community.

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2. ATMOSPHERIC FM-CW RADAR

2.1. Historical Review

The first use of the FM-CW radar technique for atmospheric studies was by Richter (Richter 1969) who worked for the then Naval Electronics Center in San Diego, CA. The Navy initially constructed the radar to better understand electromagnetic propagation, but the superb clear-air atmospheric images produced by the radar soon made it and the technique a "crown jewel" for atmospheric research. In the early 1970's, the National Oceanic and Atmospheric Administration's Wave Propagation Laboratory (now the Environmental Technology Laboratory) constructed an FM-CW radar of their own (Bean et al. 1971). Initially the researchers focused on high resolution images of clear-air turbulence, gravity waves, insects, and birds. Later a Doppler technique was applied to the radar (Strauch 1976 and Chadwick et al. 1976). This allowed the observation of lower resolution winds or high resolution turbulence in the same radar. The U.S. Army procured an FM-CW in the late 1980's (see Figure 1) and it has been used for various field experiments since that time (Eaton et al. 1995 and Astling et al. 2002). Other atmospheric FM-CW radars have also been successfully constructed such as Delft University of Technology in the Netherlands (Heijnen et al. 2000) and the new FM-CW built by the University of Massachusetts (Fraiser, personal communications).

2.2. Technology Review

The basic principles regarding FM-CW radar are well established (see any modern radar text). The radar utilizes two antennas, one for transmission and one for reception. This allows for a nearly 100% duty cycle for the final amplifier and for a very close-in first range gate. Figure 2 shows an example of the simultaneous transmission (Tx) and reception (Rx) of the radar signals. The received signal is homodyned with a delayed sample of the transmit frequency, filtered, and then sampled with a high quality ADC. Because of the FM-CW technique, the ADC need only sample at audio frequencies. Typically, successive sweeps are averaged, and processed with a fast-Fourier-transform. The resulting data contains only amplitude information (although, by changing the sweep time and processing, Doppler information could be extracted) which can be calibrated for refractive index structure parameter (C_n^2), reflectivity (dBZ), or radar cross section (RCS) measurements.

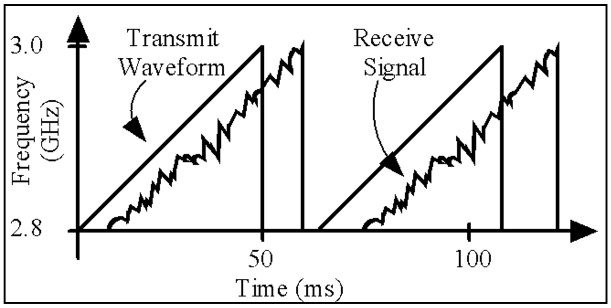

Figure 2 FM-CW Tx and Rx waveform

2.3. *History U.S. Army FM-CW Radar*

The U.S. Army FM-CW radar was originally developed for the Atmospheric Sciences Laboratory at White Sands Missile Range in the late 1980's. With changes in the Army research laboratory structure, it was transferred to Dugway Proving Ground in Utah, where it has been used in several Army boundary layer experiments. With the original data system requiring more and more resources to maintain, Dugway elected to have a new, simpler, data system developed. This data system was installed in the summer of 2001, and first used that fall.

3. NEW DATA SYSTEM

3.1. *Choice of Components*

The original data system was physically large, composed of several different components (e.g., array processor) and required a one-of-a-kind timing and control board. It was based on the venerable HP-1000 true-real-time computer system, which although very capable, was no longer easy to maintain or interface with. After surveying modern computer systems, available data acquisition boards, and data acquisition software, it was decided that the new data system could be composed of a single PC with a single multifunction acquisition board (MAQ). The final chosen data system consists of an industrial PC running Microsoft Windows 2000, a National Instruments 16-bit MAQ board (model PCI-6052E), and the graphical programming language LabVIEW, also supplied by National Instruments. The MAQ board has available several digital input/output (DIO) channels that were used to read or control the receiver and final amplifier. All digital signal processing (DSP) was performed on the host computer. The only additional items required are serial communications and TTL to differential-TTL for triggering the receiver subsystem. It should be noted that the actual microwave signal is generated in the radar receiver through direct digital synthesization. The data system need only calculate certain sweep parameters and upload these to the receiver. Once initialized, the receiver then waits for a trigger from the data system for each sweep.

3.2. *Radar Timing and Control*

A radar normally requires a special timing board, but due to the sophistication of the original receiver and the low sample rates required of the ADC, it was determined that all of the control and timing functions can originate from the single MAQ board. The MAQ board has two counter/timers and two digital-to-analog converter (DAC) outputs along with its ADC functions. The DAC channels are programmed to act as: 1) the initial start-cycle pulse (software driven) and 2) the ADC sample envelope. The counter/timers then act as: 1) the pulse sweep envelope and 2) the actual ADC samples. No physical changes were made to the board—all redirecting of the analog output signals and the counters is performed through programming of the MAQ board in LabVIEW. An important "trick" to make this work was to have the ADC samples and sweep time be an even divisor of the base time clock of the MAQ board. The final implementation allows for "N" multiple hardware-timed sweeps with "M" hardware-timed ADC samples per sweep. The time between each cycle of N sweeps is software timed and is determined by the load on the CPU at that time. In this way, the system is fully coherent within each of the N cycles. Although not tested yet, this means the system can be programmed to run in a Doppler mode and gather velocity information. Figure 2 shows the basic timing of the radar. DAC 0 and DAC 1 are simultaneously started by the software. DAC 1 is programmed with the total number of sweeps per cycle and produces a start pulse for each sweep. DAC 1 is used by the receiver to initiate a sweep, and by Counter 0 to produce a sampling envelope for Counter 1. Counter 1 produces the actual ADC sample pulses. Because the two DACs and the Counters are all based on the MAQ's onboard clock, the radar stays fully coherent within a cycle of N sweeps (which could be used for future Doppler measurements). Not shown are DIO lines used to monitor the receiver.

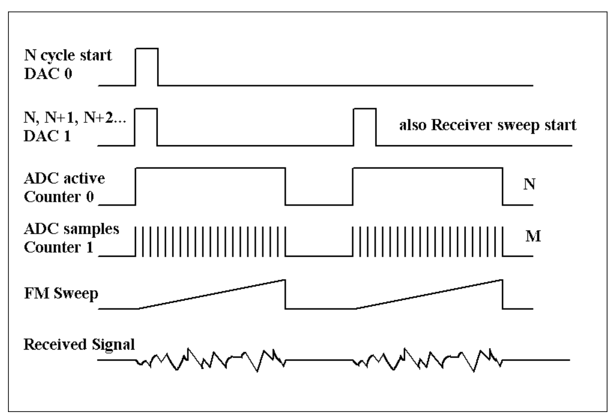

Figure 3 Basic FM-CW radar control and timing.

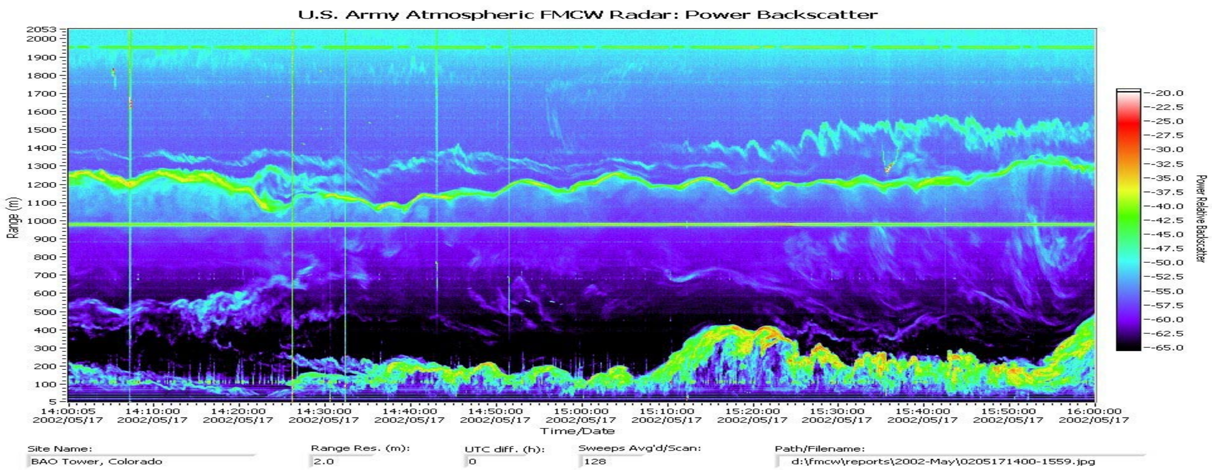

Figure 4 Clear-air turbulence as seen by the FM-CW radar. Two hours of data with 2-meter resolution, from near ground to 2050 meters, May 17, 2002, Erie CO).

3.3. Other Data System Functions

With the power and speed of modern PC's, all data acquisition, DSP functions, display functions, and data archive functions are performed in real time on the same PC. Using built-in LabVIEW networking functionality, a second PC can be configured to process any data from the time series on up, including display functions. This capability could be used in the event that additional specialized digital signal processing is implemented which causes the first PC to be too slow in data processing. This second PC can also act as a data gateway with modem and network links to distribute the backscatter data. Data can be saved at any level from time-series on up for playback or reprocessing.

4. STATUS AND DATA FROM ARMY FM-CW

4.1. Capabilities and Specifications

The FM-CW radar is mounted on two trailers, uses two steerable 10-foot parabolic dishes, and utilizes a 200-Watt traveling-wave-tube amplifier (TWTA) transmitting at 2.9 GHz with up to a 200 MHz bandwidth. The sweep time is normally set to 50 ms, with 1024+ range gates and 1-10 seconds of averaging. The range resolution is user selectable from 0.5 to 10 or more meters, and is usually selected based on the maximum required height. As in the previous data system, the lowest useable gate is around 50 meters, and the minimum detectable signal (although still in need of a new calibration) is thought to still be near –151 dBm.

4.2. Data Examples

The FM-CW technique allows for remarkable spatial and temporal resolution with high sensitivity. The radar can directly "see" boundary processes including clear-air turbulence and hydrometeors. And, other than in the dead of winter, the radar will obtain backscatter from insects and birds, which sometimes even saturate the receiver. Figures 4 through 9 show various reduced resolution colorized examples of backscatter data obtained since the new data system has been installed.

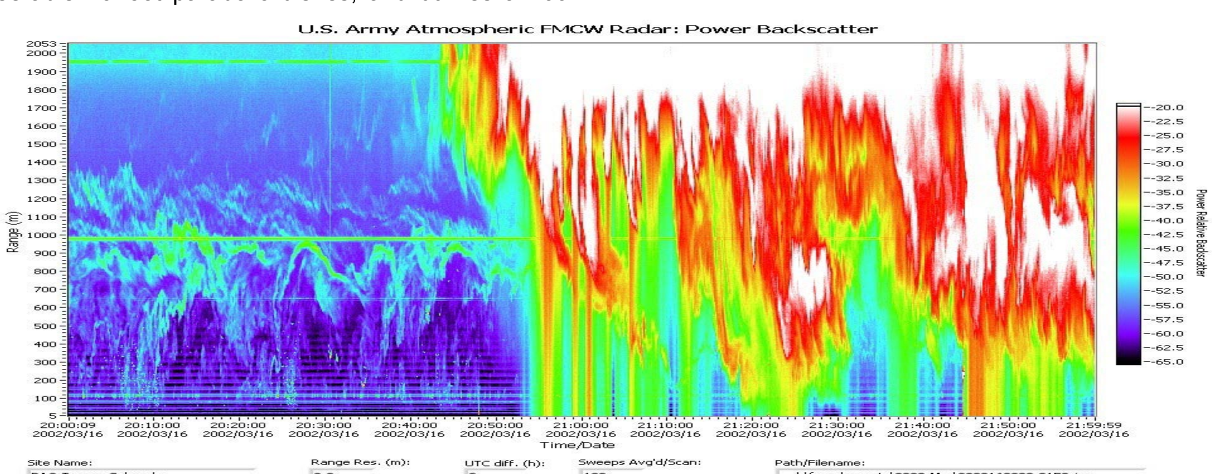

Figure 5 Clear-air turbulence and rain. Horizontal streaks are interference from TWT. (0-2053 meters AGL, 2 hours left-to-right, March 16, 2002 Erie CO)

5. REFERENCES

Astling, E. C., C. A. Biltoft, D. Storwold, and S. A. McLaughlin, 2002: Boundary Layer Observations of Cold Air Pools in a Mountain Basin. Tenth Conference on Mountain Meteorology, AMS, Park City, UT.

Bean, B. R., R. E. McGavin, R. B. Chadwick, and B. D. Warner 1971: Preliminary Results of Utilizing the High Resolution FM Radar as a Boundary-Layer Probe. *Boundary-Layer Meteorology,* **1**, 466-473.

Chadwick, R. B., K. P. Moran, R. G. Strauch, G. E. Morrison, and W. C. Campbell, 1976: A New Radar for Measuring Winds, *Bull. AMS*, **57**, 9, 1120-1125.

Eaton, F. D., S. A. McLaughlin, and J. R. Hines, 1995: A New Frequency-Modulated Continuous-Wave Radar for Studying Planetary Boundary Layer Morphology, *Radio Science* **30**, 1, 75-88.

Frasier, S., 2002: personal communications, U. of Mass.

Heijnen, S. H., L. P. Ligthart, H. W. J. Russchenberg, and W. F. v. d. Zwan. 2000: A High-resolution Multi parameter S-band Atmospheric Profiler: System Description and Measurements. 1st Europ. Conf. on Radar Meteor.

Richter, J. H., 1969: High Resolution Tropospheric Radar Sounding, *Radio Science,* **4**, 12, 1261-1268.

Strauch, R. G., 1976: Theory and Applications of the FM-CW Doppler Radar, Ph.D thesis, U. of Colorado.

Acknowledgements

The author would like to thank Mr. James Bowers of the U.S. Army Dugway Proving Ground for supporting the FM-CW radar and this effort.

The author would also like to acknowledge the important help of Mr. Dave Merritt in designing and implementing the new FM-CW data system.

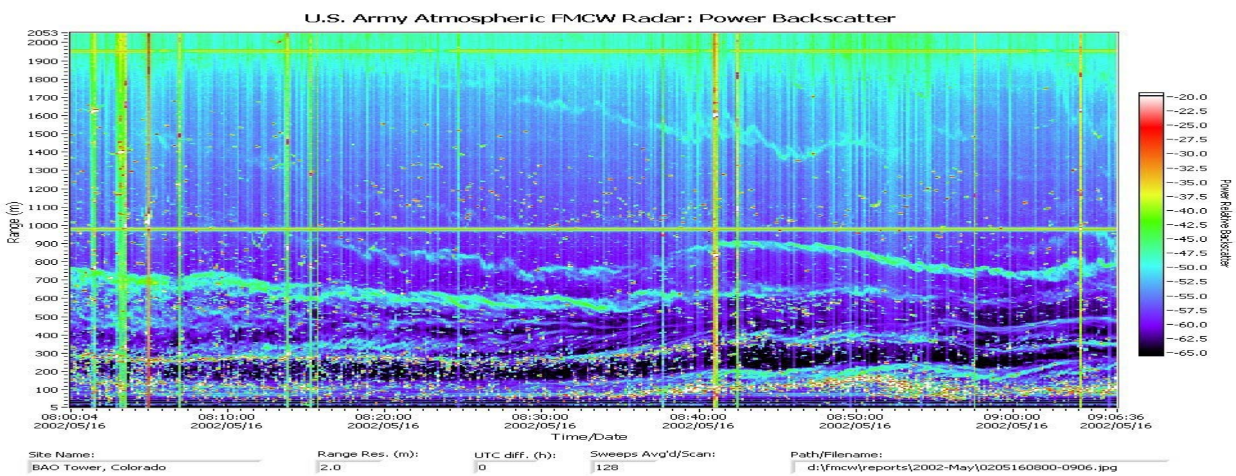

Figure 6 Clear-air turbulence with point targets. Insects appear as dots while birds cause saturation of the receiver causing vertical streaks. (0-2053 meters, 2 hours left-to-right, May 16, 2002, Erie CO)

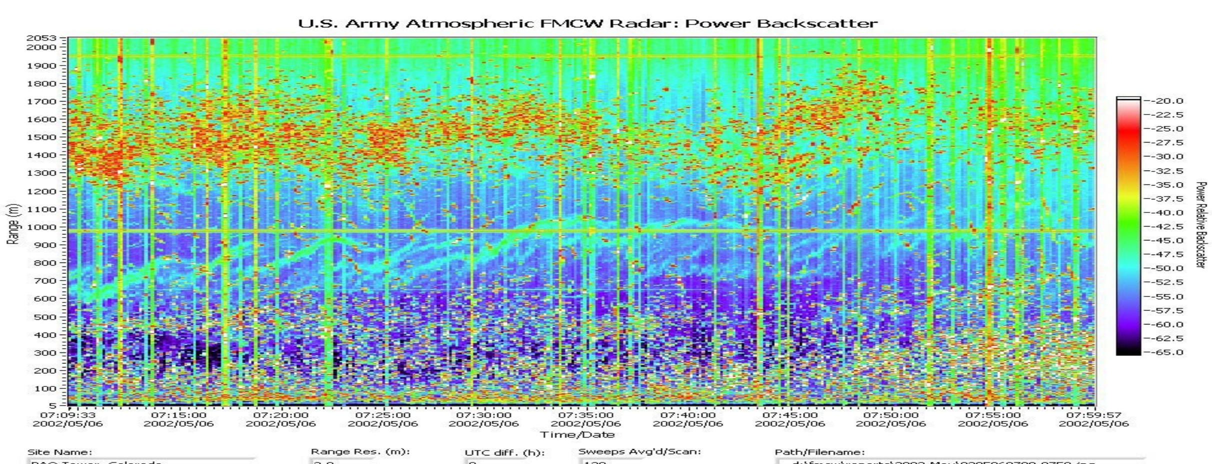

Figure 7 Clear-air turbulence, insects, and receiver saturation from birds. The insects above 1200 meters are probably migrating. (0-2053 meters, 2 hours left-to-right, May 06, 2002, Erie, CO)

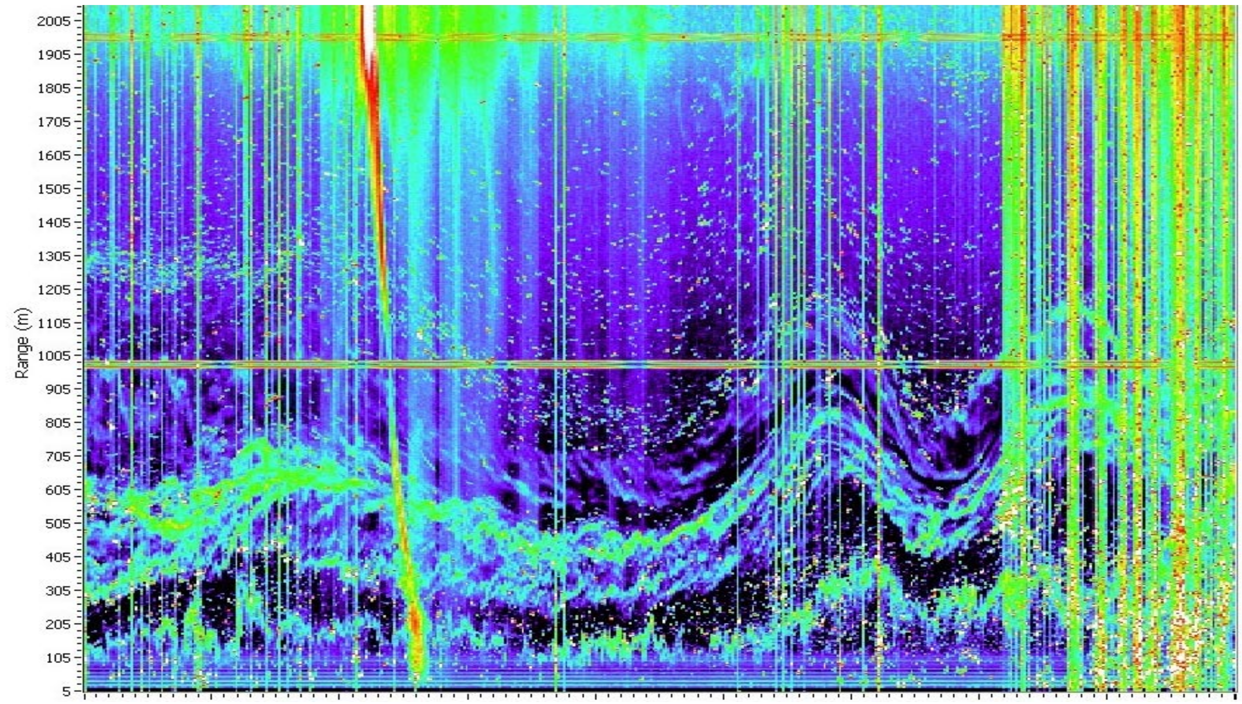

Figure 8 Clear-air wave structures, brief rain, insects and birds, as observed by the Army FM-CW radar at Dugway Proving Ground, UT. (0-2105 meters, 2 meter resolution, 1 hour of data left-to-right), mid-morning, early Fall 2001)

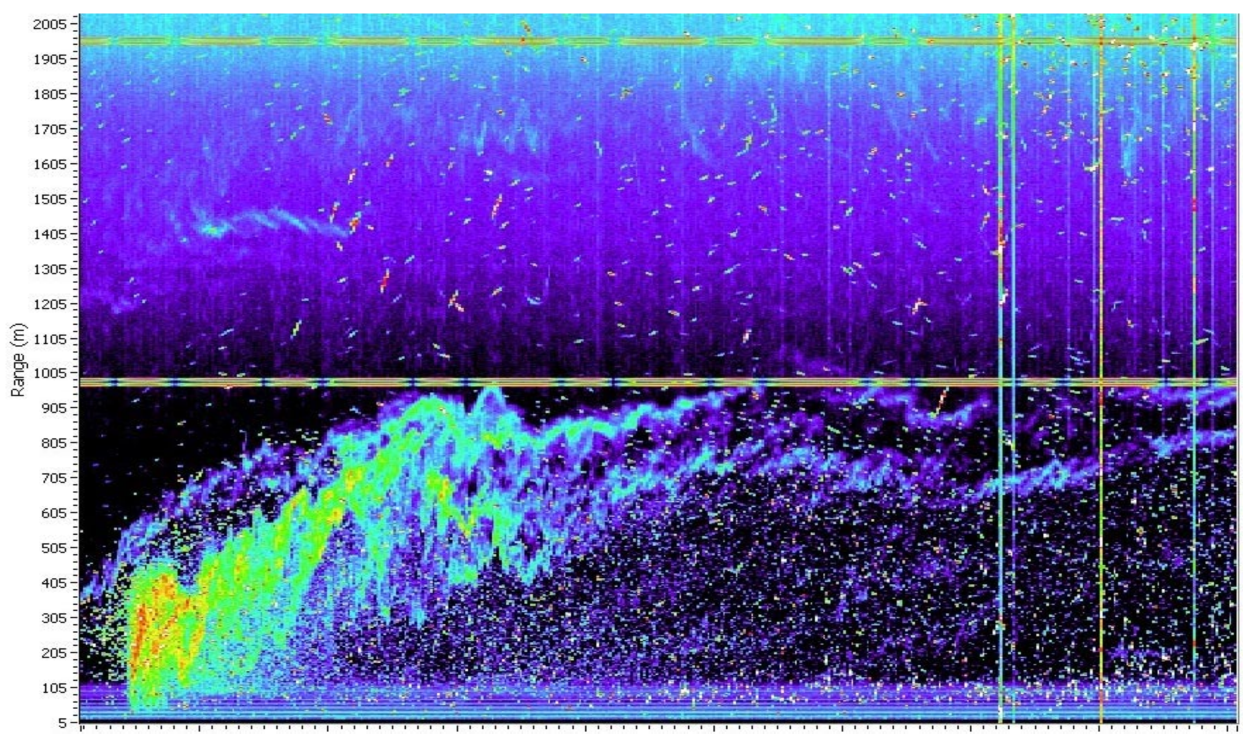

Figure 9 Apparent frontal signature and insects as seen by U.S. Army FM-CW radar at Dugway Proving Ground, UT. (0-2105 meters, 2 meter resolution, 1 hour of data left-to-right, early evening, Fall 2001)