An 8-mm Cloud Profiling Radar for the ARM Program: First Returns

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Abstract

ETL and PNNL have been working over the last 18 months on the development of a new radar system for the ARM Program and have recently obtained first results. Images produced by the radar's data system show excellent time height plots of radar reflectivity, Doppler velocity, and spectral width during a variety of cloud conditions. Results will be significant to the ARM Program as the radar will provide useful information on cloud boundaries. Doppler information can be used to derive useful microphysical parameters such as particle size distributions.

Introduction

NOAA's Environmental Technology Laboratory (ETL) is working with Pacific Northwest National Laboratory (PNNL) to develop an 8-mm Doppler cloud profiling radar for the ARM Program. The primary purpose of the radars will be to provide high-resolution, high-sensitivity monitoring of clouds above the ARM Cloud and Radiation Testbed (CART) sites. The radar provides estimates of the backscattered power, mean velocity, spectral width and noise level. Full recording of the entire Doppler spectra for each range is also available, but is limited to short operating periods due to the increased data rates. Reflectivity measurements obtained from the radar's backscattered power can be used to identify cloud boundaries. Doppler velocity measurements of vertical motion can be combined with other remote sensors to provide estimates of particle size distributions. The radar will run continuously and unattended to provide measurements from near the surface to 20 km.

The prototype of the five ARM radars is located at ETL's radar field facility at Erie, CO. First returns were obtained starting February 9, 1996, using a small (4-ft) antenna while operating with reduced power. The first radar is scheduled to be installed at the Oklahoma CART site in the summer of 1996. Similar radars are scheduled for deployment in the tropical western Pacific, the north slope of Alaska and the SHEBA program.

Operating Characteristics

Development of the new radars was largely inspired by successful observations of non-precipitating clouds conducted with ETL's scanning, 8-mm cloud radar, which is operated by a scientist/engineer (Kropfli et. al. 1990) and similar millimeter-wave radars operated by other groups. The major design challenge for the new radars was to attain sensitivity and resolution similar to that of the ETL research system while meeting ARM requirements for very long-term, unattended operations and minimized repair problems. To achieve these goals required major design departures from the research system. These include use of a different transmitter, a larger non-scanning antenna, pulse compression, a completely different processor and emphasis on using commercially available components. Using pulse compression techniques and high duty cycles, the ARM radar design compensates for peak power levels lower than the research radar but achieves nearly the same average power. The calculated performance of ETL's present research radar is -30 dBZ at 10 km, while the estimated sensitivity of the ARM radar to be deployed at the SGP central site, is >-35 dBZ at 20 km. The improved sensitivity is largely due to antenna size and a lower noise receiver.

A comparison of the operating characteristics of ETL's research radar and the ARM radar is shown in Table 1. ETL's radar has a scanning antenna and polarization diversity

Table 1. A comparison of operating characteristics of ETL's scanning research radar and ARM's fixed beam zenith radar.

Characteristics	ARM radar	ETL research radar
Frequency, GHz	34.86	34.6
Peak Transmitted Power, Watts	100	85 kW
Average Power, Watts	25	40
Pulse Width, μs	38 (0.6 compressed)	0.25
Inter-Pulse Period, μs	154	200
Modulation	Pulse and Coded Pulse (64 bit)	Pulse and Double Pulse
Range Resolution (available), m	90,(45, 255, 495)	37.5
Number of Range Gates	444 single pulse 166 coded pulse	328
Time Domain Integrations	8	0
Antenna Type	Fixed beam Cassegrain feed parabolic dish, vertically pointing	Scanning, offset Cassegrain parabolic dish
Antenna Diameter	10 ft. or 2 m	1.2 m
Antenna Gain, dB	57 or 53.5	49
Beamwidth, sidelobes	0.2^o, -20dB	0.5^o, -30 dB
Polarization	Single: linear	Dual: circular, elliptical, linear
Transmitter Type, lifetime	TWTA, 20,000 hrs	Magnetron, 2,000 hrs
Doppler Processing	FFT, 32 points	Pulse-pair, time series
Nyquist Velocity, resolution	2 ms^{-1}, 10 cms^{-1}	10 ms^{-1}, 10 cms^{-1}
Integration Time, typical	3 s, on line	>3 s, post processing
Sensitivity (calculated)	>-35 dBZ at 20km	-30 dBZ at 10 km

to aid in identifying ice/water mixtures. The ARM radar has a fixed vertical beam high gain antenna and a single linearly polarized receiver channel. The ETL radar uses a pulsed magnitron transmitter (85 kW) with average life expectancy of 2000 hours. The ARM radar uses a low power traveling wave tube amplifier (TWTA, 100 W) with a 20,000 hour life expectancy. ETL's radar transmits a short pulse (50 ns) while the ARM radar transmits a wide pulse (up to 50 μs) using pulse compression to provide high range resolution. The ARM radar provides four separate range resolutions, which allows for some sensitivity options at long ranges. The low power TWTA is expected to provide the reliability needed for 24 hour per day unattended operation. The radar will incorporate a calibrated noise source to provide routine calibration of the receiver and data processor. The antenna used in the radar will undergo a range calibration to provide accurate far field gain measurements The radar's operations can be controlled remotely by sending new parameters over a network link.

The parts used in the system are commercial off-the-shelf components (COTS), which help to minimize the spare parts inventory and reduce cost. The system was designed using a small number of integrated subsystems to provide for ease in field servicing. The radar block diagram in shown in Figure 1.

The radar's operation is programmed through the profiler online program (POP) software developed through a cooperative research and development agreement (CRADA) between NOAA's Aeronomy Laboratory, ETL and Radian Corporation. This software has been used successfully for several years to control the operation of wind profiling radars. Several modes can be programmed and sequenced to obtain the desired height coverage, range resolution and averaging time (sensitivity). Two separate processors (PCs) are used to operate the system. The radar hardware processor (OS/2) controls the data collection cycle (POP) and operates the RF hardware. The second processor (Solaris) is used as a link between the output of the radar processor and the site data system. The second processor was designed to function as the data manager for raw and calibrated radar data, system monitor data and log files. It also performs local data file backup in case of a site data system failure. Radar data are stored as netcdf files for local display and plotting. Time height displays of the radar signal power, velocity and spectral width can be accessed from the local console or remotely over the network. The netcdf data are ingested into the site data system which maintains an archive of daily data sets. The software interface to the site data system complies with the requirements for the CART site at Southern Great Plains (SGP) as well as the requirements for the ARCS for the tropical western Pacific (TWP), north slope of Alaska (NSA) and the SHEBA program.

Measurement Goals

Recent technological developments have combined measurements from ground-based remote sensors operating at different wavelengths to determine cloud properties that could not be determined with any single sensor operating alone. Millimeter-wave Doppler radar measurements can be combined with co-located narrow-band (near 10.6 microns) IR radiometer measurements to determine profiles of cloud particle sizes, concentrations and IWC in all-ice clouds (Matrosov et al. 1994). In addition, mm-wave radar measurements have been combined with co-located microwave radiometers (which measure integrated liquid and vapor in the atmosphere) to measure profiles of droplet sizes, concentrations and LWC in all-water clouds (Frisch et al. 1995a). Doppler radar techniques can also be used to accurately determine the turbulent properties of clouds (Frisch et al. 1995b), and can easily monitor the frequent multiple layers which exist in cloud systems (Uttal et.al 1995).

First Returns

In February of 1996 the prototype of the ARM radar began operations at ETL's radar field facility at Erie, CO. Data were collected for short intervals and used to verify the system's operations over a two week period using reduced power and a 4-ft diameter antenna. The antenna pointed vertically and was covered with a plastic tarp to prevent moisture from collecting on the dish surface. (At the CART sites, the radars will use larger antennas with radomes.) A variety of interesting meteorological events were recorded during this period and are presented here in half tone images (the originals are in color).

Figure 2 is a time height plot of reflectivity of cirrus at 9 km MSL. The record extends for 2.5 hours. Range resolution was 90 m with 10-sec averages. Although not evident from the image, the signal to noise ratio (backscattered power) covers a range of values from -15dB to +21 dB. This measurement can be converted to dBZ by calibrating the receiver. Displays similar to this one will be available to the local operator through the radar console display.

The Erie field site is located along the front range of the Rocky Mountains and strong winds often produce wave-like structures in the clouds. Figure 3 is a two hour time height plot of reflectivity that records one such wave like pattern.

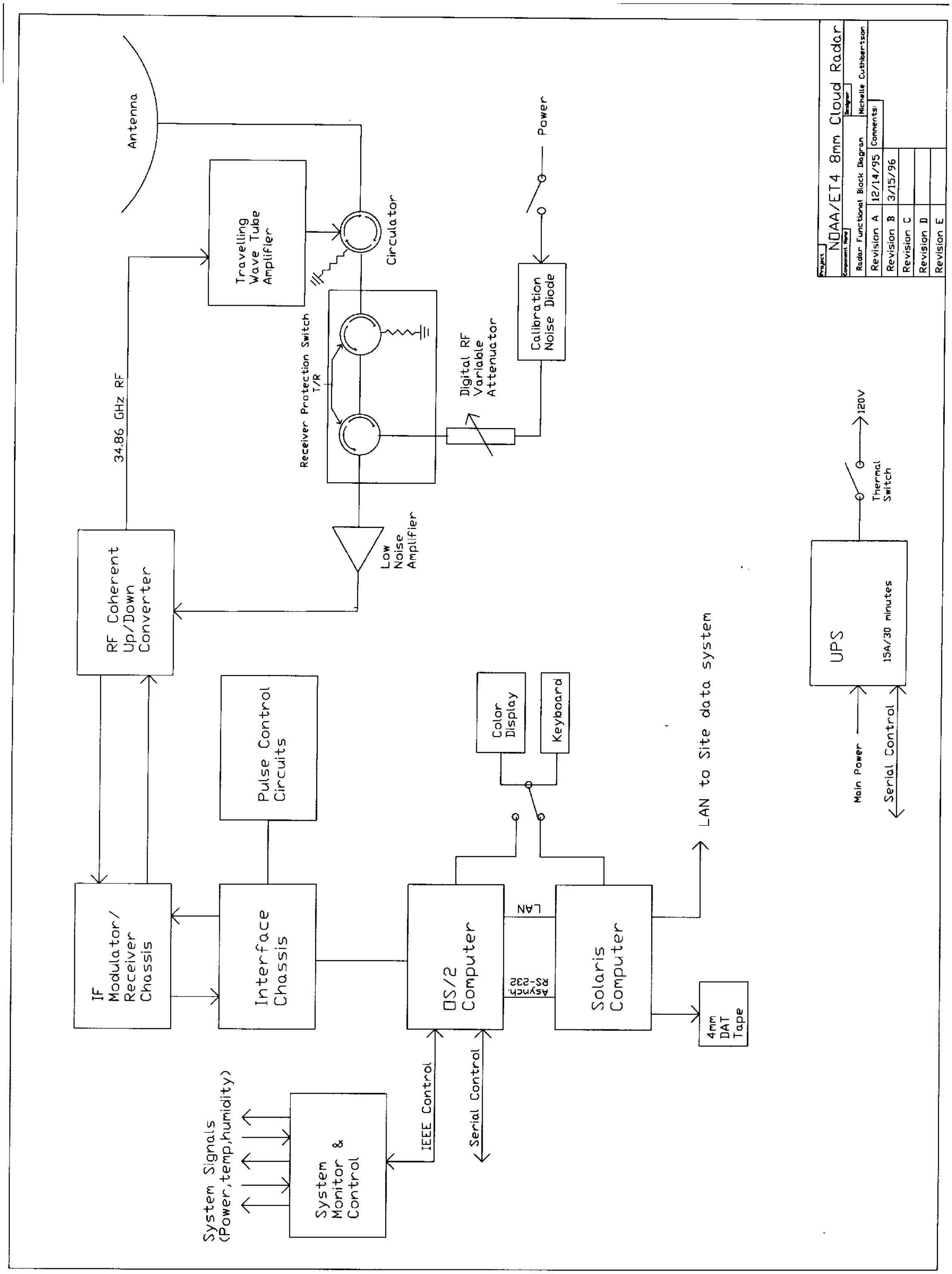

Figure 1. A block diagram of operating characteristics of ETL's scanning research radar and ARM's fixed beam zenith radar.

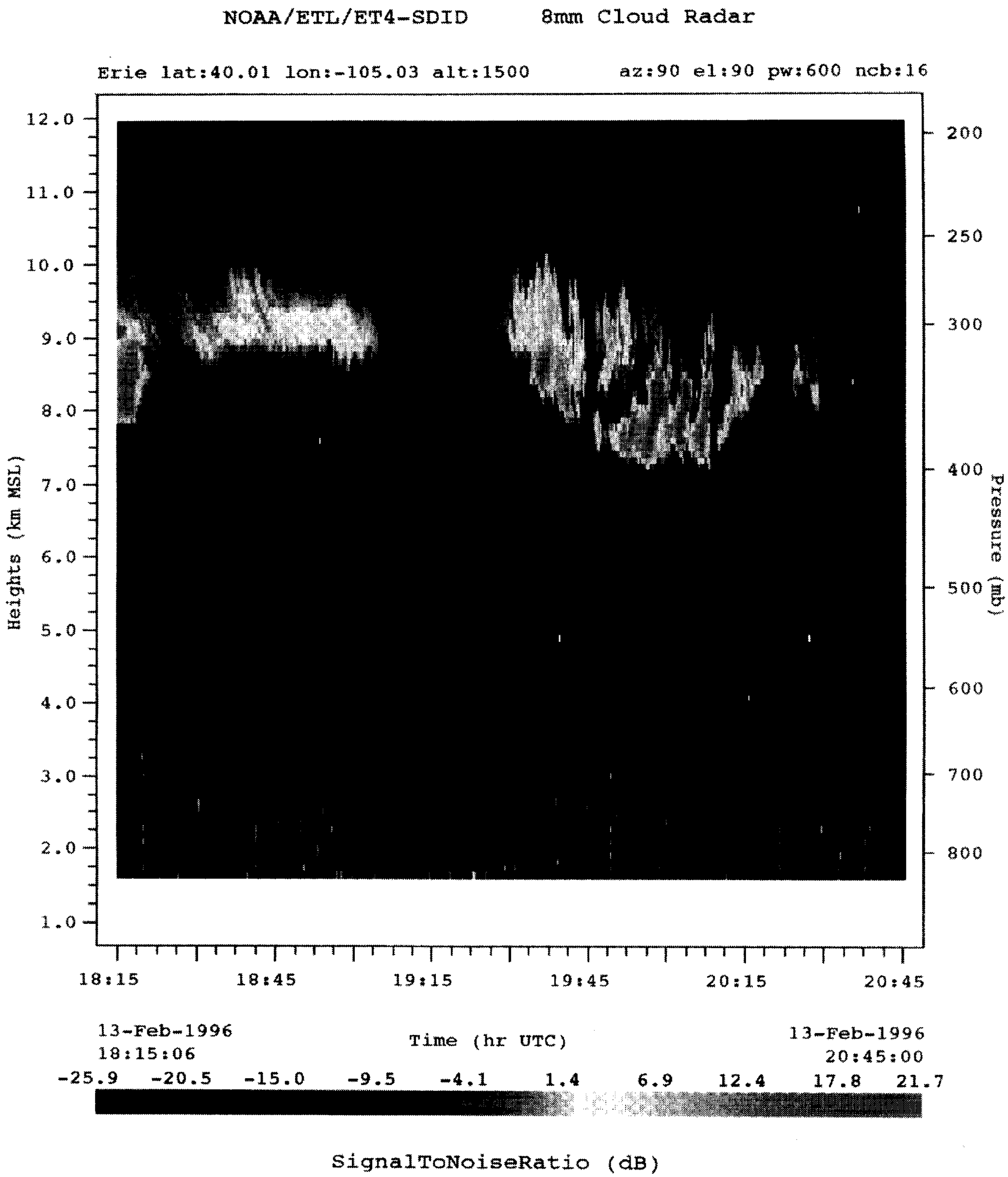

Figure 2. Cirrus clouds observed from 18:00 to 21:00 UTC February 13, 1996, at Erie, Colorado. The cloud's backscattered power is displayed in terms of S/N (an uncalibrated measurement). Range resolution is 90 m with 10-sec averaging time.

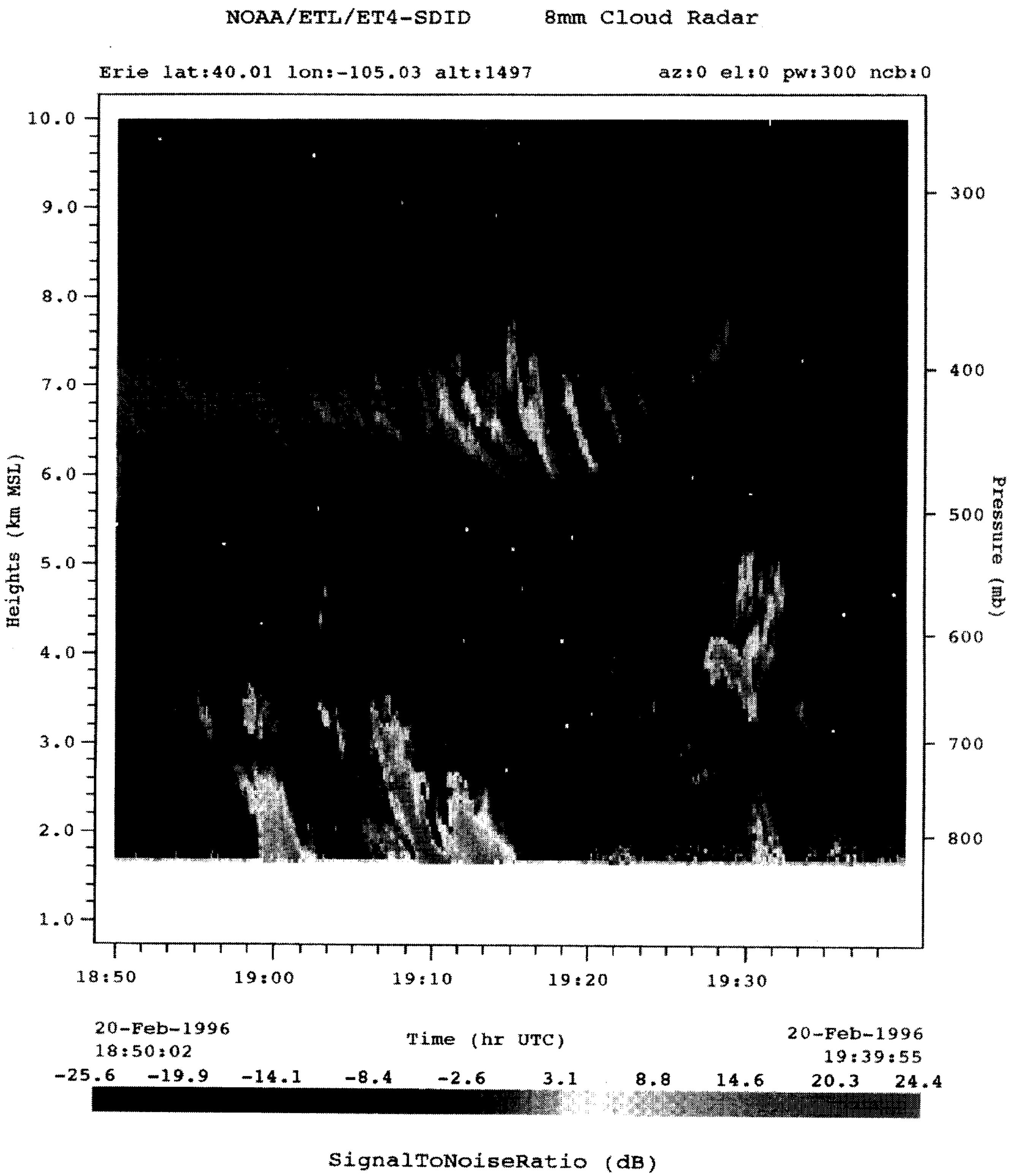

Figure 3. Wave-like structure observed at 7 km on February 20, 1996, 19:20 UTC at Erie, Colorado. This field site is located near the front range of the Rocky Mountains and wave patterns are often observed. Range resolution is 45 m with 10-sec averaging time.

The range resolution is 45 m with 10-sec averaging. The velocity plot for the same time interval (not shown) indicates a strong oscillation in the vertical velocities. The period is characteristic of gravity waves.

Figure 4 shows the passage of convective clouds over the site. The radar was operated with low average power (0.3 W) to reduce potential receiver/processor saturation from strong echoes. The dynamic range of the measurements is over 50 dB. Light precipitation was measured at the surface at 3:30 U.T.C. This low power "precipitation" mode will be interleaved with a high power "cloud" mode to allow nearly simulataneous measurements of strong and weak targets.

Summary

The development of a cloud radar for the ARM Program's CART sites is significant because the radars will provide information on the role clouds play on the radiative properties of the atmosphere. These radars will greatly improve the CART basis for long-term detailed monitoring of cloud properties. The information will be used in the development of parameterizations for GCMs, and in validations for satellite observing systems. The first radar, developed at ETL in Boulder in collaboration with PNNL, will provide continuous observations of clouds from near the surface up to 20 km. Initial results from the radar indicate precipitating clouds as well as non-precipitating ice clouds are being observed and that velocities are within the ranges expected for these cloud types. Upcoming comparisons with ETL's research 8-mm radar will be the first test of the DOE/ARM calibrations and operating procedures.

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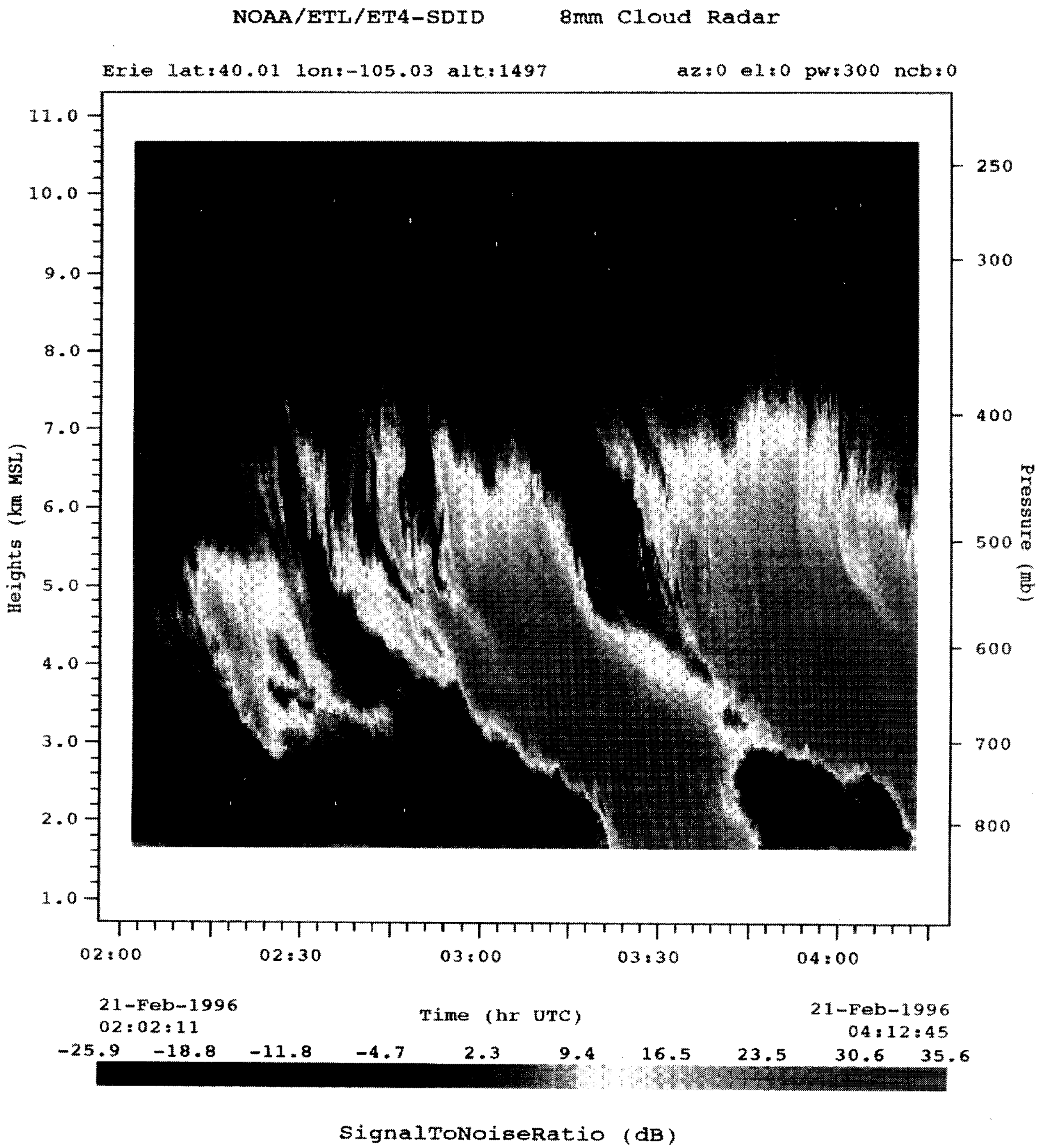

Figure 4. Convective clouds observed at the Erie site February 21, 1996, from 2:00 to 4:00 UTC. Light precipitation was measured at the surface at 3:30 UTC. The radar was operated with low power. Range resolution is 45 m with a 20-sec sampling interval.