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A New Snow-Level Detection Radar

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1. INTRODUCTION

Snow-level detection by radar is a very useful tool for hydrologic applications, especially in mountainous watersheds. As part of NOAA's Hydrometeorological Testbed (HMT) field operations, vertically pointing radars routinely determine the snow level in various locations of California. This presentation describes a new, low-cost radar for snow-level detection.

The radar bright band shows enhanced reflectivity near the melting layer. White et al. (2002) compared vertical profiles of radar reflectivity and Doppler vertical velocity with rawinsondes to validate automatic retrieval of the bright band height. The height is shown to be a good estimate of the snow level. Lundquist et al. (2009) show the importance of these measurements for hydrology forecasting in mountainous terrain. These measurements are also useful for weather forecasters making predictions of precipitation amounts (Keighton et al. 2009).

In the past, these measurements have been made with vertically pointing pulse-Doppler radars. These radars form the basis of the vertical profilers currently used by in HMT to provide the snow level. These radars are complicated and expensive. Early work done at the NOAA Wave Propagation Laboratory (WPL) showed that these measurements can be done by Frequency Modulated Continuous Wave (FM-CW) radars (Strauch 1976). Strauch showed that 0.5 W was enough power in an FM-CW radar to observe snowflakes. In the 1980s, FM-CW lost funding and corporate interest in favor of pulse-Doppler wind profilers.

2. NEW RADAR DEVELOPMENTS

Based on work by Strauch (1976) and Costa and Chadwick (1984), the NOAA Earth System Research Laboratory's Physical Sciences Division (PSD) started to develop an FM-CW radar in 2006 to be a snow-level detection radar. The goals of this development are to provide reliable measurements of precipitating systems over the radar by observing a minimum reflectivity of 10 dBZ at 5 km, with 75 m resolution.

This new FM-CW radar development is at 2835 MHZ (S-band). This frequency was chosen for many reasons. PSD is the successor organization to WPL and has many of the original FM-CW components available for constructing a prototype. This is also the frequency of some of PSD's pulsed S-band systems, providing another source of components for a prototype. This frequency was also chosen since it has very small attenuation due to precipitation.

Figure 1 shows a block diagram of the prototype radar. Modern components make generation of the FM-CW signal very simple by using a Direct Digital Synthesizer (DDS). The DDS provides an extremely linear frequency sweep with very accurate control of the frequency. The RF components are standard commercial parts that can be easily obtained from multiple vendors.

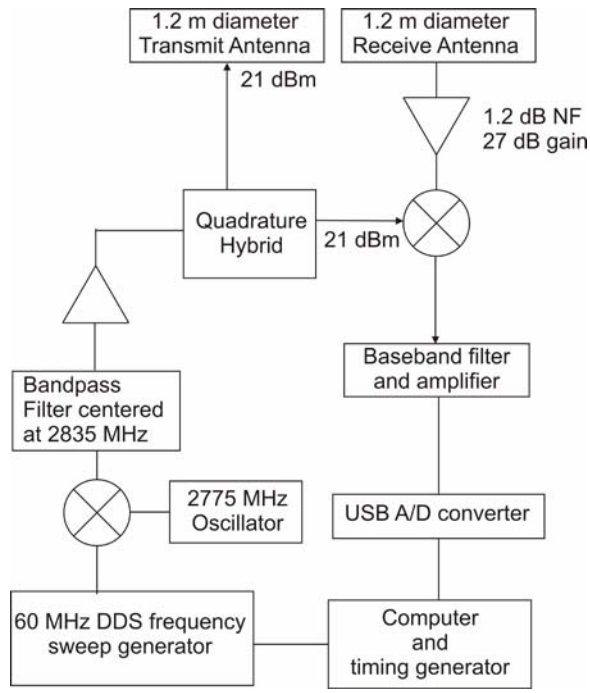

Figure 1 Block diagram of prototype FM-CW radar.

Our software uses the two-dimensional signal processing described by Costa and Chadwick (1984). This involves performing an FFT of the data from each sweep to get an array of complex-voltage signals for each range. This array of complex voltages can be processed using PSD's standard software for processing pulse-Doppler data. Power spectra are calculated and averaged, as described in Carter et al. (1995). Using our pulse-Doppler software and data formats for the FM-CW radar system allows the data to be utilized with minimal additional software development.

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Due to the low transmitted power, this radar has much lower Signal-to-Noise Ratios (SNR) for the echo returns than the pulsed Doppler systems. This required minor changes to the automatic snow-level detection algorithm, but we were able to start with the standard routine. Utilization of existing routines has greatly reduced the amount of software effort required. In addition, some of the software being utilized has been in use for several years, so it is much more robust than newly developed software.

This prototype radar transmits 150 mW of power. The system noise temperature is 185 K. This gives a minimum detectable signal of about -157 dBm. For our initial operations, the radar was set for 50 m resolution. The antennas are 1.2 m diameter parabolic reflectors. This gives a 5.9° half-power beam width. Since the frequency ramp is under software control, it is very easy to change the resolution from 50 m to any value in the range of 10 m to 150 m. Since FM-CW sensitivity varies only with the volume size, higher resolutions do not have the great loss in sensitivity that pulsed systems do. We have chosen 50 m to keep the number of ranges required to observe to 10 km a reasonable number. Our software currently has a limitation of 513 range gates.

3. CALIFORNIA TESTS

During the winter of 2008/2009 this prototype FM-CW radar was field tested at the HMT site in Colfax, California. The prototype FM-CW radar measured vertical profiles of Doppler spectra with a spatial resolution of 50 m and a temporal resolution of 36 seconds. Automatic detection of the snow level was performed every 10 minutes. While in California, the FM-CW radar operated from the same instrument electronics enclosure as a 915-MHZ pulsed Doppler wind profiler, rain gage, and disdrometer. Figure 2 shows the prototype FM-CW radar at the Colfax site. The two 1.2 m antennas are placed on the ground next to the electronics enclosure. The covered antenna is used for transmission, the open antenna is for reception. In this configuration, there is about 70 dB isolation between the antennas.

Figure 2. Prototype FM-CW radar installed at the Colfax, CA HMT field site in December 2008.

One problem encountered during this test was that it snowed at the radar site. The antenna with a cover was piled with snow, causing the transmitted signal to be attenuated. The uncovered antenna was filled with snow, and also had attenuation problems. During the period with snow at the site, the radar operated very poorly.

During the observing period, the prototype FM-CW radar measured snow levels between 175 m and 2200 m above the radar. Figure 3 shows direct comparisons of snow levels measured by the 915-MHZ wind profiler and the FM-CW for 22 January 2009. It is clear that the radars measure the same heights. Since the FM-CW only operates in one mode, it is able to make snow level measurements every 10 minutes. The co-located 915-MHZ radar operates in multiple modes and only produces a snow level once an hour. The FM-CW radar was calibrated using the co-located disdrometer, and is believed to be within 2 dB of absolute calibration.

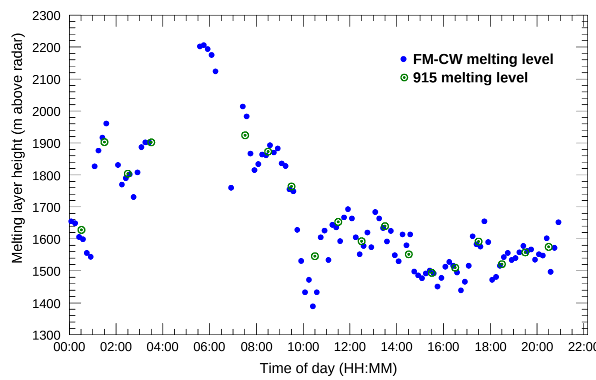

Figure 3. Snow level determined by two different radars at the Colfax, CA HMT site on 22 January 2009.

4. COLORADO DEVELOPMENTS AND TESTS

For the 2009/2010 rainy season in California, NOAA will deploy two FM-CW radars similar to the prototype described above. The field test in Colfax identified several areas that need improvement: 1. Antennas need to be able to work when it snows. 2. The radar electronics need to have protection from the elements. 3. The radar antennas need to be mounted on a platform to maintain alignment and pointing. 4. The non-atmospheric signals from inside the radar need to be reduced.

The first three problems have been solved. We have new shrouds for our antennas. They have openings that are cut at 45°. When covered with plastic, these will enable the snow to slide off and not attenuate the signals. To maintain antenna geometry, the two antennas are mounted on the platform of a utility trailer. A weatherproof electronics enclosure is mounted between the antennas. This enclosure is heated and air conditioned, so normal office type temperatures are maintained. This allows the use of standard components. This new system is shown in Figure 4, in the parking lot next to the NOAA building in Boulder, CO.

Cutting the shroud at this steep angle does good things to the radar. In an FM-CW system, isolation between the transmit and receive antennas is a limitation. With the openings of the antennas not parallel to each other, the cross-talk between the two antennas has been reduced to about 90 dB. Also, since the ground clutter is the convolution of the two antenna patterns, there are few common side-lobes between the transmit and receive

Figure 4. Operating prototype FM-CW radar with new antenna shrouds and electronics enclosure.

antennas.

5. RECENT RESULTS

The Figure 5 shows the reflectivity observed by the radar for a series of precipitation events that passed over Boulder on 30-31 August 2009 (day 242). Of the 210 heights saved by the radar, 182 are shown. The plot is labeled relative reflectivity, but the calibration constant has been applied, so the scale is close to dBZ. The straight lines are signals that are internal to the radar electronics. These signals are being tracked down and improved electronics being installed in the radar before deployment this winter (2009/2010). In the lower right corner of Figure 3, there is a lot of speckle. These echoes are commonly observed by PSD's S-band radars and are attributed to

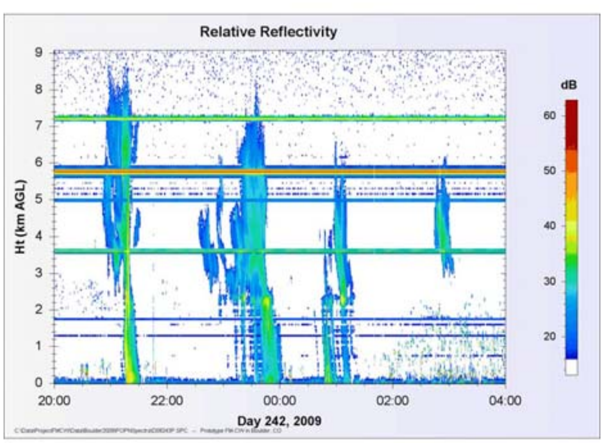

Figure 5. Reflectivity observed by the FM-CW radar in Boulder on 30-31 August 2009.

insects These signals exhibit a diurnal character and vary with season.

This radar has full Doppler capability. In this operating mode, the full scale velocity is 16.5 ms^{-1}. We are using standard wind-profiler spectral analysis, calculating the moments from the average power spectra. Figure 6 shows the velocities measured by the radar during the period shown in Figure 3. The color scale has been chosen so that the red colors show frozen snow, and the blues show liquid water drops.

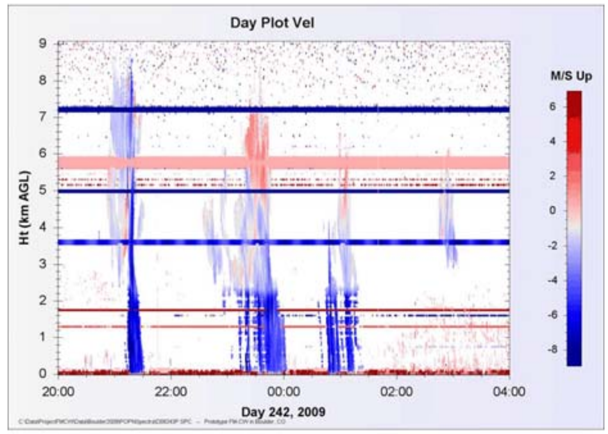

Figure 6. Radial velocity observed by the FM-CW radar operating in Boulder on 20-21 August 2009.

In Figure 7, a contour plot of an individual spectral average is shown. Here the first contour is 2 dB above the noise floor, with 3 dB steps in the contours. Of the 210 ranges, 182 are shown in this plot. This shows Doppler velocity, which has a sign difference from the radial velocities shown in Figure 6. This was a convective storm. The bright band is visible at 2.4 km above the ground. The strong, isolated signal at 13.4 ms^{-1} and 7.2 km height is one of the internal signals that cause the lines seen in Figures 5 and 6. Other internal signals are also seen in this figure, especially below 2 km in the negative Doppler velocity region.

Figure 8 shows details from the lowest twenty heights of the radar. Here the average power spectra have been plotted as individual spectra. These linear spectra clearly show the precipitation down to the lowest range gate, at the mouth of the antenna (0 range). In this lowest range, there is not a complex signal, so the direction of the velocity is not measured. This ambiguity results in the double side lobe signal. The spectrum at 50 m range has some minor problems, causing the velocity and width to be obviously wrong. Some of these problems are caused by leakage from the bottom gate and extraneous signals from the internal electronics of the radar. The only clutter removal done on these spectra has been the removal of the zero velocity (DC) point. There is no clutter visible, even though the radar is located in a poor clutter location.

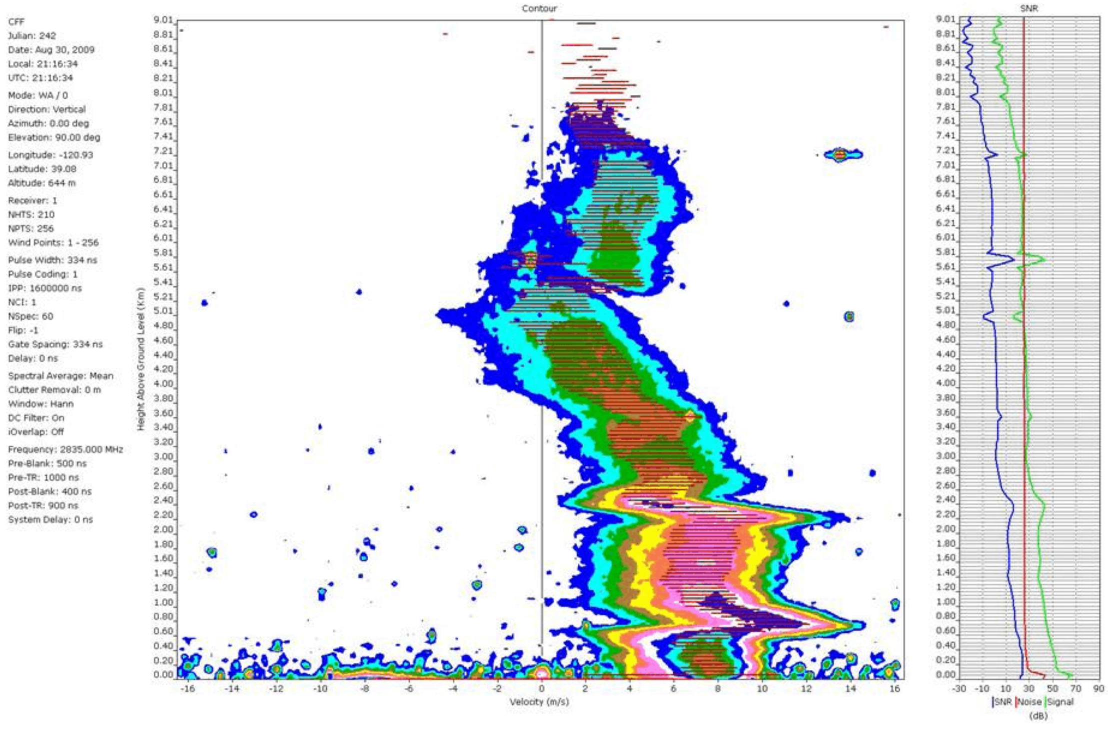

Figure 7. Contour plot of the average power spectra from 30 August 2009, 21:16:34 UTC. The first contour is 2 dB above the noise, contour interval is 3 dB.

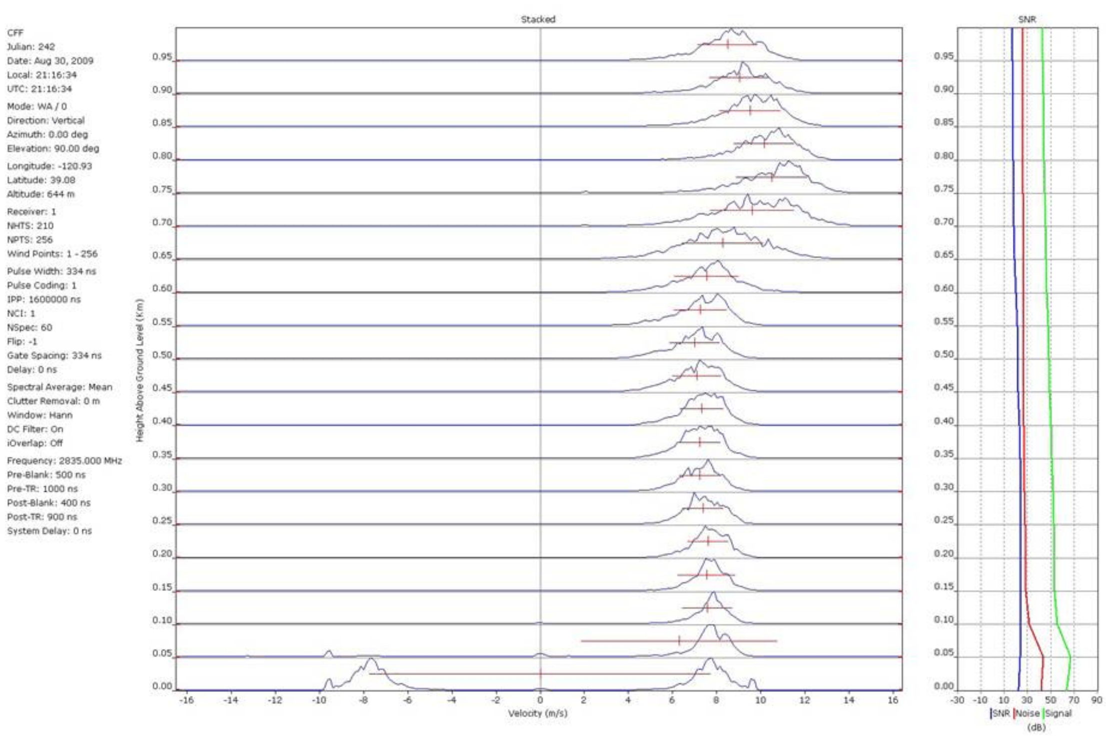

Figure 8. Stacked spectra plot of the lowest 20 heights from 30 August 2009, 21:16:34 UTC.

6. SUMMARY

This S-band (2.835 GHz) FM-CW radar is a lower-cost alternative to the pulsed radars currently used by NOAA for this snow level determination. This radar is not as sensitive as the pulsed radars, but it can be constructed at a fraction of the cost. Operating at S-band to minimize attenuation, this radar is small and low-powered. To develop this new radar, previous FM-CW equipment and pulsed Doppler hardware and software were used to create a robust instrument. The prototype radar utilizes commonly available parts to create a 0.15 W transmit signal, and is bi-static, using two 1.2 m diameter parabolic dish antennas. The prototype data system uses a commercial data-acquisition system combined with control circuits from a pulsed radar system to digitize the received signals. The software for the radar utilizes the same Doppler signal processing used in the other HMT vertically-pointing radars.

Acknowledgments. This work is supported by the California Department of Water Resources and NOAA's Hdydrometeorological Testbed Program (HMT). Special thanks go to Dave Costa (CIRES/NOAA) for his efforts with the new antenna shrouds and enclosures.

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