Introduction

The W-band spectra for VOCALS events 15 Nov, 18 Nov and 23 Nov are being processed to estimate both the vertical air motion and the microphysical composition of stratus clouds. This document describes the status of the current work and the data files and images available to help with your analysis.

The W-band spectra have been processed using a single peak moment estimating routine. The spectra are processed twice. The first estimate processes each spectra separately and the second estimate averages 4 seconds of spectra (13 consecutive spectra) before estimating the moments. The estimated moments for the three events are saved in MATLAB mat-files. Plots of time-height cross-sections of estimate moments and time-spectra plots have also been generated. The MATLAB data and TIF plots are available on the FTP site:

ftp://ftp1.esrl.noaa.gov/users/cwilliams/VOCALS/

The following sections describe the processing that was performed, the names of the variables in the MATLAB mat-file, and the images that were generated to help you analyze the observations.

This work is in progress and this document will be updated as more work is completed.

Original Data

The W-band radar spectra were collected at a 3-Hz sample rate. For each spectrum, the following quantities were estimated:

- mean_noise mean noise floor from Hildebrand-Sekhon method
- max_noise maximum noise in Hildebrand-Sekhon method
- Vmin minimum Doppler velocity above maximum noise (left edge)
- Vmax maximum Doppler velocity above max noise (right edge)
- zdb reflectivity (dBZ) (from left edge to right edge)
- snr signal-to-noise ratio (dB) (from left edge to right edge)
- Vmin minimum Doppler velocity above maximum noise (left edge)
- Vmax maximum Doppler velocity above max noise (right edge)
- Vpeak_snr snr of spectral peak (dB) (single velocity bin over noise power)
- Vvar Doppler velocity variance (2^{nd} moment) (m^2/s^2)
- wid Spectral width (m/s) (2sqrt(Vvar))
- skew Doppler velocity skewness (m^3/s^3)
- lt_snr snr of left half of spectrum (dB)
- rt_snr snr of right half of spectrum (dB)
- snr_dif snr difference between halves (right – left) (dB)
- kurtosis Doppler velocity kurtosis (m^4/s^4)

Ship Heave Correction

The velocity estimates were corrected for Kongsberg ship heave estimates. Two sets of variables are in the MATLAB file: original (no ship heave correction) and adjusted. Since we want to use ship heave corrected data, the shorter filename has the ship heave correction.

The original velocity variables are named:

- Vmin_orig Original Vmin, no ship heave adjustment
- Vmax_orig Original Vmax, no ship heave adjustment
- Vmean_orig Original Vmean, no ship heave adjustment
- Vpeak_orig Original Vpeak, no ship heave adjustment

The ship heave adjusted velocity variables are named:

- Vmin = Vmin_orig – Ship_Heave Ship heave adjusted Vmin
- Vmax = Vmax_orig – Ship_Heave Ship heave adjusted Vmax
- Vmean = Vmean_orig – Ship_Heave Ship heave adjusted Vmean
- Vpeak = Vpeak_orig – Ship_Heave Ship heave adjusted Vpeak

Temporal Averaging

Luke et al. (2013) reduced temporal variability in the estimated moments by averaging consecutive spectra before calculating the spectral moments. In Luke et al., the W-band data was collected with a 2-second dwell and they averaged 9 consecutive spectra so that average spectra represented a 20 second observation. This temporal average makes the underlying assumption that the cloud or drizzle DSD is non-varying over a 20 second interval. By using a moving 9 spectra average, the original 2 second resolution can be retained in the smoothed dataset.

To remove the air motion variability during the 20-second averaging interval, Luke et al. shifted each spectrum so that the largest spectral peak in each spectrum occurs in the same spectral bin. I tried shifting by the largest observed spectral peak, but with a 3 Hz sample rate, the VOCALS spectra have more noise than a 2 second dwell so that the peak in neighboring spectra do not necessarily correspond to the same features from spectra-to-spectra.

To overcome the spectrum-to-spectrum variability in the largest spectral peak, I shifted the spectra so that they all have zero mean Doppler velocity. The spectra were averaged and then the averaged spectra shifted back to have the same mean velocity as the reference spectrum (the middle spectrum). The moments were calculated using the shifted averaged spectrum.

As a first pass, 13 consecutive spectra were averaged together so that the averaged spectrum represents a 4 second dwell. In the future, I plan to do some lag correlations to see how fast the microphysics change with time and height…but that will come later…The window of 13 consecutive spectra was performed on every spectrum so that the averaged moments retain the 3 Hz sample rate.

The MATLAB file contains moment estimates for the raw and the 4-second averaged spectra. To identify the two variables, they have different prefixes. The single peak raw moments have the prefix 'sp_' and the single peak 4-second average moments have the prefix 'sp_ave_'. For example: 'sp_Vmean' and 'sp_ave_Vmean' are the mean Doppler velocity for the two datasets.

Despeckling of Observations in Time-Height Space

Figure 1 shows the single peak moment estimates of signal-to-noise ratio (SNR), mean Doppler velocity and spectral width of the original spectra (not time averaged). A despeckle filter was designed to remove non-atmospheric observations by evaluating the mean Doppler velocity of their nearest orthogonal neighbors (i.e., top, bottom, right and left neighbors). The filter is applied only to observations with SNR less than a threshold of -10 dB. Thus, all observations above -10 dB are retained independent of their neighbors. The Figure 2 is similar to Figure 1 except after performing the despeckling filter.

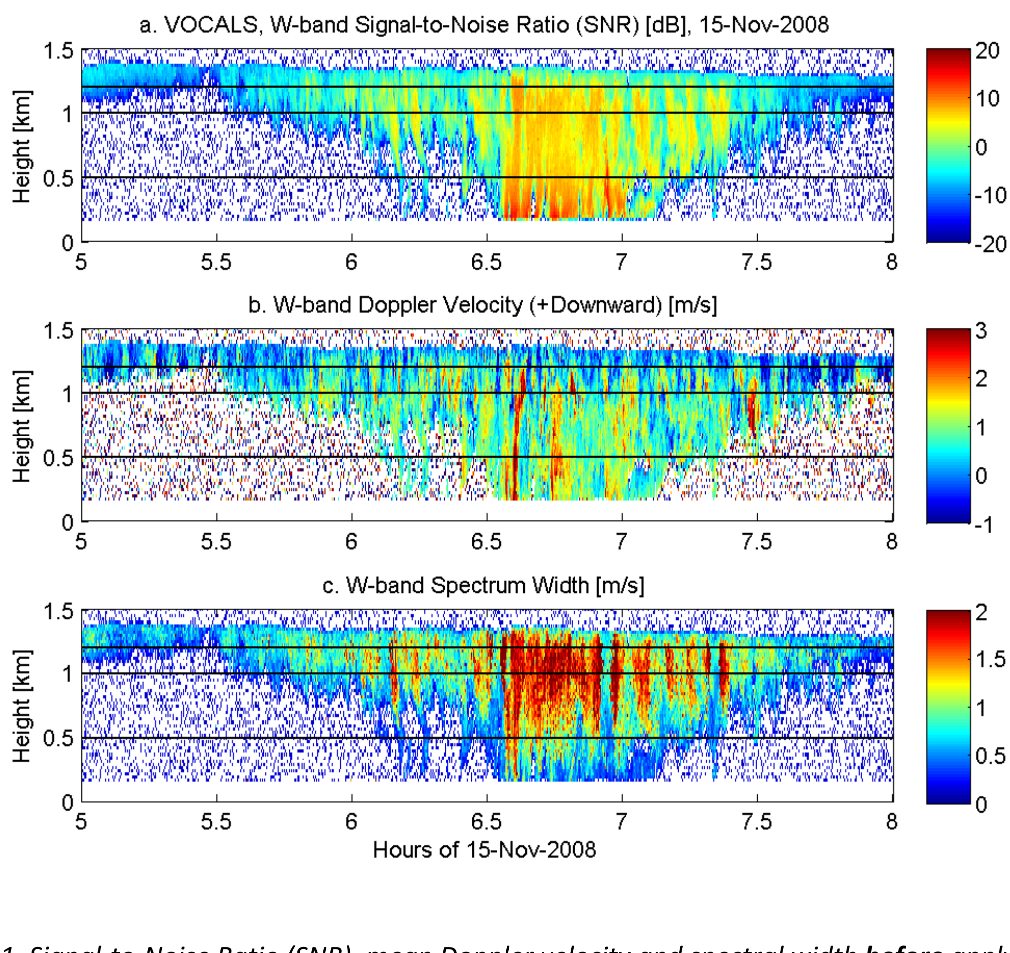

Figure 1. Signal-to-Noise Ratio (SNR), mean Doppler velocity and spectral width ***before*** *applying the despeckle filter.*

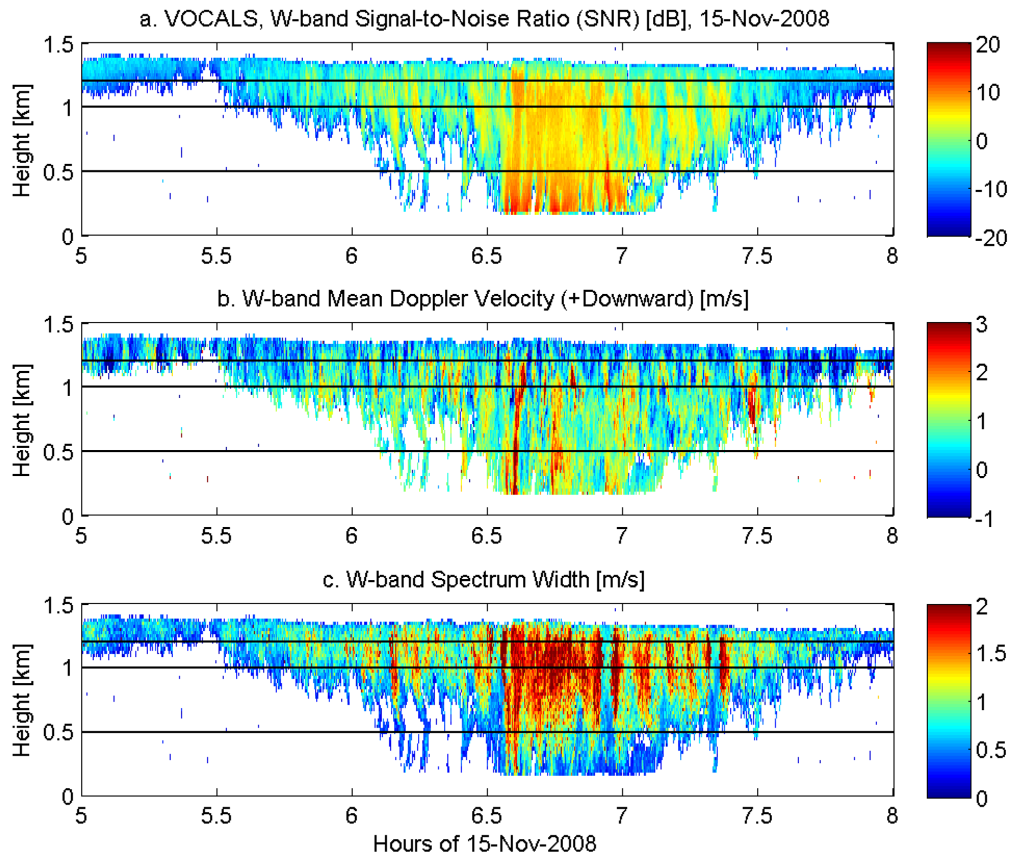

*Figure 2. Signal-to-Noise Ratio (SNR), mean Doppler velocity and spectral width **after** applying the despeckle filter. Despeckle filter threshold applied only to observations with SNR less than -10 dB and there needs to be at least 3 orthogonal neighbors with mean Doppler velocities within +/- 3 m/s of the central observation.*

The despeckling filter has a huge impact (is that a scientific enough phrase?) on the scatter plots. Figure 3 and 4 show the scatter plots of mean Doppler velocity vs. SNR at the three heights of 1.18 km (top), 1.0 km (middle) and 0.5 km (bottom) for the 3 hour period from 5-7 UTC on 15 Nov. The scatter at SNR less than -10 dB is removed after performing the despeckling filter. *Note that the MATLAB files contain the despeckled moments so that you don't have to worry about the outliers at low SNR in your analysis.*

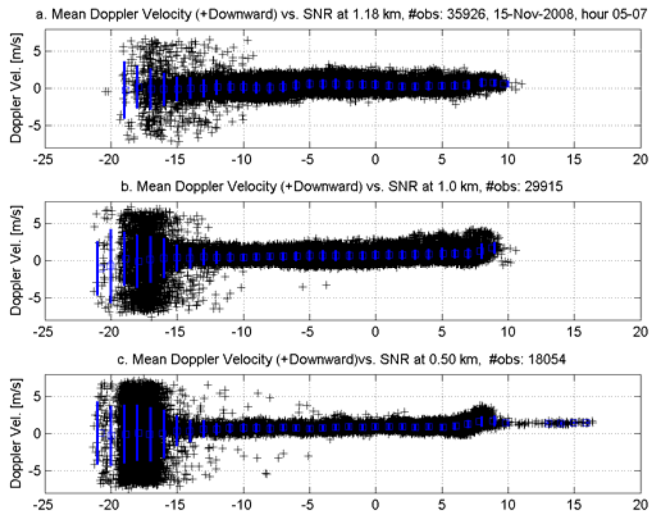

*Figure 3. Scatter plots of mean Doppler velocity (vertical axis) vs. SNR at three heights **before** applying despeckle filter.*

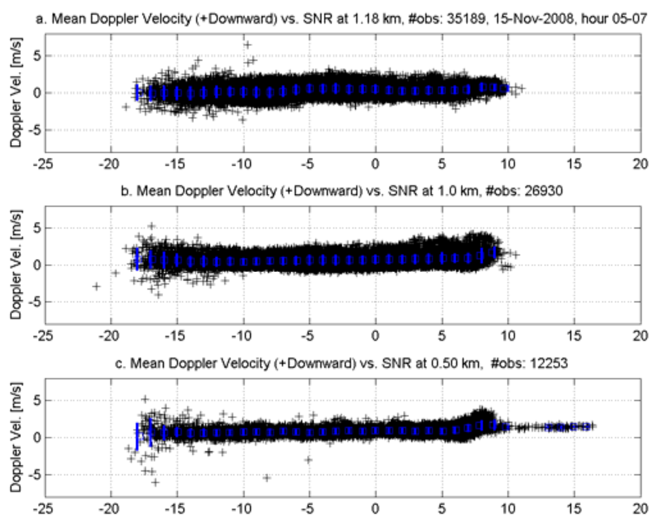

*Figure 4. Scatter plots of mean Doppler velocity (vertical axis) vs. SNR at three heights **after** applying despeckle filter.*

Time-height Cross-Sections Plots

Hourly time-height cross-sections of the despeckled moments are generated for the three VOCAL events on 15 Nov, 18 Nov and 23 Nov. For each hour, the plots show either:

Reflectivity (top), mean Doppler velocity (middle) and Spectral Width (bottom)

Or

Reflectivity (top), Skewness (middle) and Spectral Width (bottom)

The plot names and descriptions are:

- wband_despeckled_orig_ZVW_XXNov_hrYY.tif
  - Despeckled W-band moments of reflectivity, Doppler velocity and spectrum width (ZVW) with no time averaging
- wband_despeckled_orig_ZSW_XXNov_hrYY.tif
  - Despeckled W-band moments of reflectivity, Skewness and spectrum width (ZVW) with no time averaging
- wband_despeckled_4sec_ZVW_XXNov_hrYY.tif
  - Despeckled W-band moments of reflectivity, Doppler velocity and spectrum width (ZVW) with 4-second time averaging
- wband_despeckled_4sec_ZSW_XXNov_hrYY.tif
  - Despeckled W-band moments of reflectivity, Skewness and spectrum width (ZVW) with 4-sec time averaging

As an example of the 3-panel plots, Figure 5 shows the reflectivity, skewness and spectrum width for hour 10 UTC of 18 Nov (the filename is: wband_despeckled_4sec_ZSW_18Nov_hr10.tif).

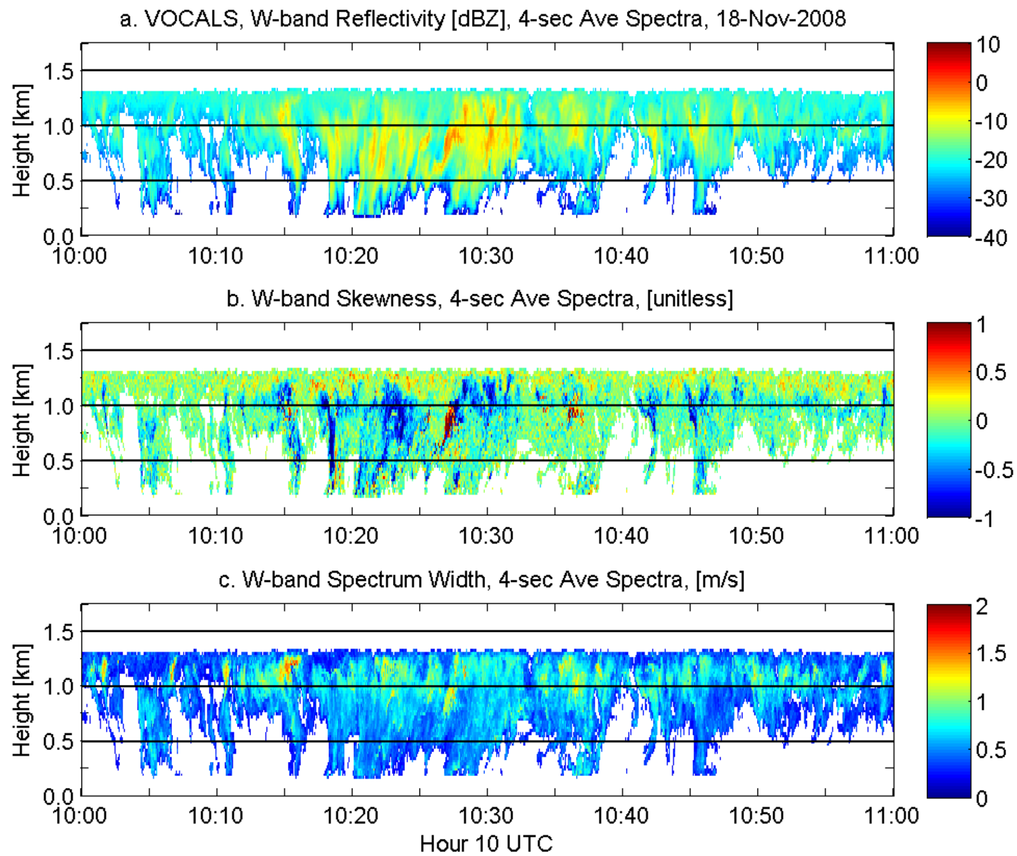

Figure 5. Time-height cross-section plot of reflectivity, skewness and spectrum width for hour 10 UTC of 18 Nov (filenamed wband_despeckled_4sec_ZSW_18Nov_hr10.tif).

Plots of Spectra

To investigate why the skewness of the spectra are negative or positive, the original and 4-second averaged spectra are plotted at one range gate for 1-minute intervals. There are typically 200 spectra per minute with Figure 6 showing the spectra from 18-Nov-2018, 1022 UTC at 1.16 km. The top panel shows the original spectra and the middle panel shows the 4-second averaged spectra. The thick black line is the mean Doppler velocity and the two thin black lines are the integration limits used to calculate the moments (Vmin and Vmax). The bottom panel shows the reflectivity and skewness (scaled by 10) for the original and the 4-second averaged spectra.

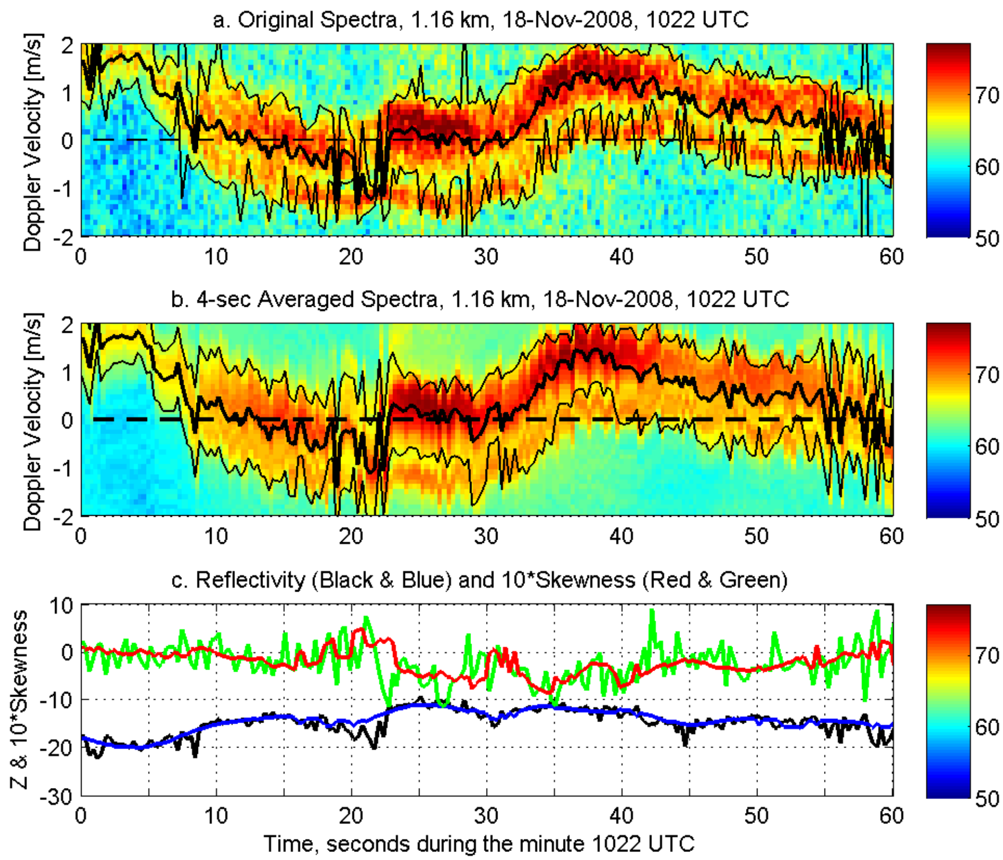

*Figure 6. Spectra (a) original and (b) averaged with 4-second moving window. Panel (c) shows the reflectivity and 10*skewness for the original and 4-second averaged spectra. Color legend for panel (c): Black line: reflectivity at original resolution; Blue line: reflectivity at 4-sec resolution; Green Line: 10*Skewness at original resolution; Red line: 10*Skewness at 4-sec resolution.*

For this minute, 1.16 km is probably within the cloud because two peaks can be identified by eye. The drizzle peak is more downward (on the top of the panel) and has a larger peak amplitude than the cloud peak. The limits of integration sometimes include and sometimes exclude the cloud peak. (This indicates I need to implement a 2-peak fitting routine to isolate the two peaks.)

Sometimes, ringing appears in the spectra that can fake-out Hildebrand & Sekhon (1974) noise floor estimator. Figure 7 shows the beginning of the ringing over 2 minutes at 0.96 km. The left panel shows spectra for 1027 UTC when the integration limits are incorrect. The right panel shows spectra for 1028 UTC when the integration limits are fine.

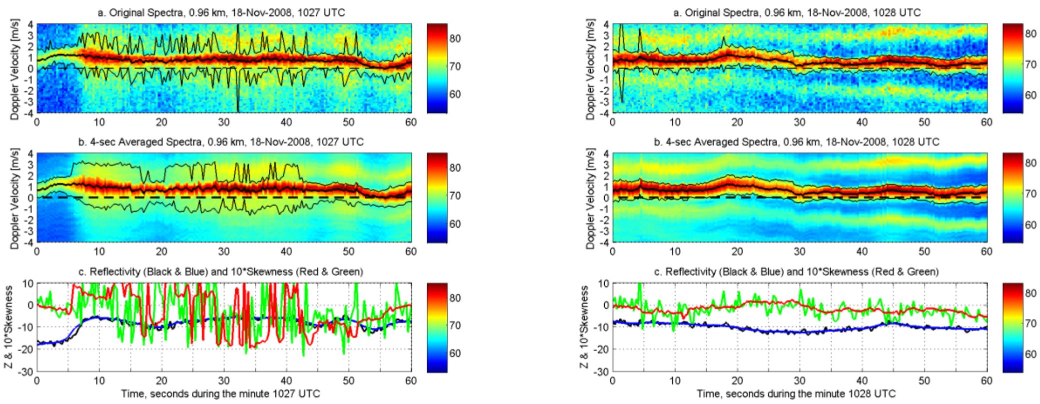

Figure 7. Spectra when the radar has ringing and interferes with the integration limits (left panel, 1027 UTC) or is not a problem with the integration limits (right panel, 1028 UTC).

In very, very general terms, the skewness tends to be negative in the drizzle because the spectra are asymmetric with the tail extending to more negative velocities (negative velocities have upward motions because positive Doppler velocities are moving toward the radar). And the skewness tend to be positive near the top of the cloud when both cloud and drizzle signals are detected in the spectra. Figure 8 shows both positive and negative skewness in the same minute of spectra at a range near the top of the cloud at 1.26 km. During seconds 5 to 40, the spectra have positive skewness. The raw spectra (top panel) show cloud peaks with larger intensity than the drizzle signals. The mean Doppler velocity is closer to the cloud peak (more negative velocity). Near second 45, the skewness goes negative and the drizzle signal becomes larger in magnitude and is larger than the cloud peak. The mean Doppler velocity is in the middle of the integration limits with peaks observable on both sides of the mean Doppler velocity.

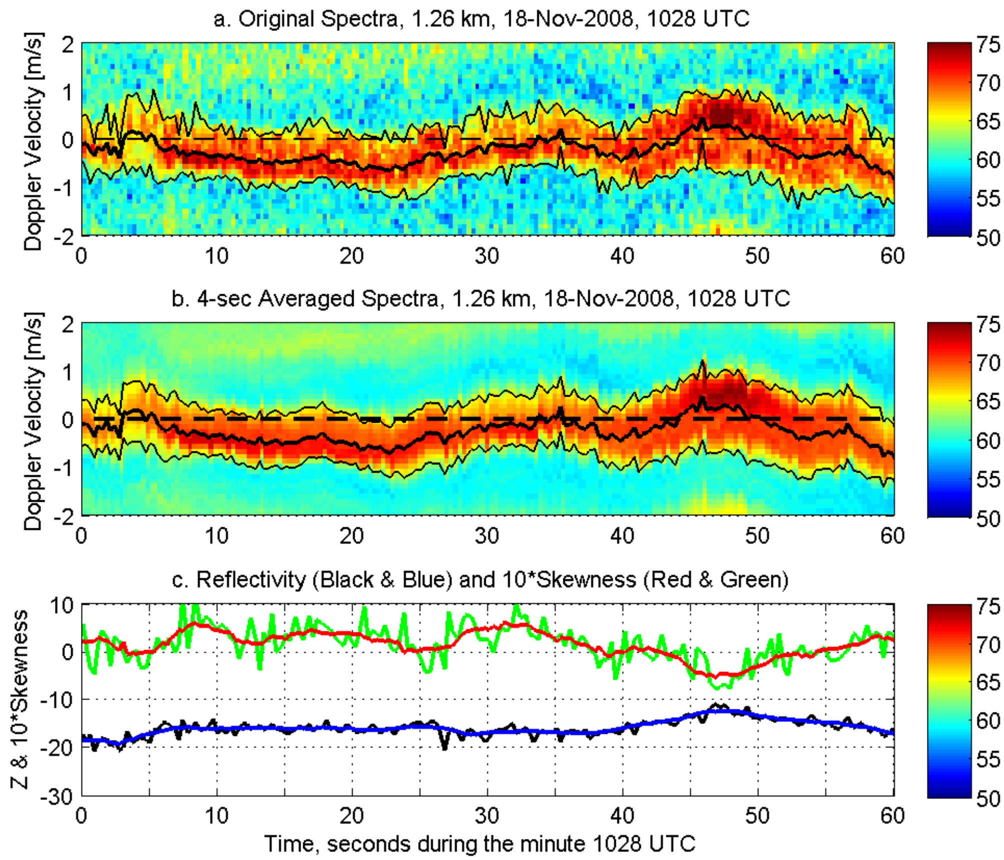

Figure 8. Time-spectra plots at 1.26 km for 18 Nov for minute 1028 UTC.

Time-spectra plots have been generated for the VOCALS events. For this pass, spectra have been generated for every minute with at least 25 valid reflectivity observations and at a 50 m vertical resolution (thus, every other range gate is processed). To aid in viewing the time-spectra plots, the plots have been named in 'height order' and in 'time order'. The height order naming allows you to quickly scan the data at a fixed height. The time order naming allows you to move up or down in height for the same profile.

Since both cloud spectra and drizzle spectra are expected in this data set, the time-spectra plots are generated with two different Doppler velocity ranges, either +/- 2 m/s or +/- 4 m/s. The filename notation is:

- spc_18Nov_DV2_1p31km_1032.tif - spectra, +/- 2 m/s Doppler velocity, height order
- spc_18Nov_DV2_hr1032_1p31km.tif - spectra, +/- 2 m/s Doppler velocity, time order
- spc_18Nov_DV4_0p76km_1019.tif - spectra, +/- 4 m/s Doppler velocity, height order
- spc_18Nov_DV4_hr1019_0p76km.tif - spectra, +/- 4 m/s Doppler velocity, time order