A New Motion-Stabilized W-band (94-GHz) Cloud Radar for Observations of Marine Boundary-Layer Clouds

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The NOAA Physical Science Division has developed and recently deployed a new pitch-roll stabilized, vertically pointing W-band (94 GHz) Doppler cloud radar for research investigations of the dynamics and microphysics of marine clouds. The radar produces profiles of full Doppler spectra and the first three moments of the spectral peak at 0.3 s time intervals; the vertical resolution is 25 m. Pitch-roll stabilization allows Doppler measurement of vertical motion without tilt-contamination by horizontal winds; ship heave is measured independently and subtracted from the radar vertical velocity to yield very accurate particle vertical motions.

What is a Cloud Radar?

- Radar scattering from a distribution of droplets:

$$Radar\ SNR \propto \frac{P_t A_e \Delta R \Delta t \lambda^{-4}}{R^2} q_{liq} r_m^3$$

- P_t=Transmit power, R=range, A_e=Antenna Area, ΔR=Range resolution, Δt='Dwell' time to produce velocity estimate, λ=wavelength, q_{liq}=amount of liquid water per volume, r_m=drop radius

- Tradeoffs:
  - Portable – A_e small
  - Affordable , safe, reliable- P_t small
  - Resolve processes – ΔR, Δt small
  - Sensitive – A_e, P_t, ΔR, Δt Large

- Rain drops r_m=1 mm; Cloud drops r_m=0.01 mm. Clouds require 10^6 more sensitivity.

- Solution – λ small. Typically 3 or 8 mm (94 GHz or 35 GHz)

Historical Background Meteorological Cloud Radars

- 1950's TPQ-11 35 GHz radar 'ceilometer' for airports

- 1983 NOAA-K 35 GHz scanning Doppler radar (100 kw, 1.2 m, 5 sec)

- 1987 Lhermitte 94 GHz Doppler

- 1995 Moran ARM/MMCR 35 GHz (continuous, spectral processing, 0.1 kw, 1m, 20 sec)

- Marine deployments
  - 1994 Penn State 94 GHz Doppler Monterey Ship Tracks Experiment
  - 1999 NOAA/PSD 35 GHz MMCR JASMINE (Indian Ocean); [2000, 2001, 2004, 2008]
  - 2008 NOAA/PSD 94 GHz VOCALS Marine Stratus (stabilized, 1.2 kw, 0.25 m, 0.3 sec)

NOAA-K   MMCR   PSD Wband

Doppler Spectrum Moment Processing

FIG. 3. Schematic of Doppler power spectra from the vertically pointing beam of a radar wind profiler for (a) a case with only clear-air returns from Bragg scattering off of inhomogeneities in the atmospheric index of refraction due to spatial moisture and temperature gradients on the scale of half the radar wavelength, and (b) a case in which Rayleigh scattering from precipitation creates a second peak in the spectrum. The term V_a is the reflectivity-weighted mean of the Bragg scattering portion of the spectrum (i.e., the vertical air motion); V_t is the reflectivity-weighted mean terminal velocity of the precipitation particles that produced the Rayleigh scattering portion of the spectrum; V_r is the measured radial vertical velocity (i.e., the combination of V_t and V_a); S is the measured signal power, and σ_w is the width of the appropriate peak of the spectrum; N is the background noise level.
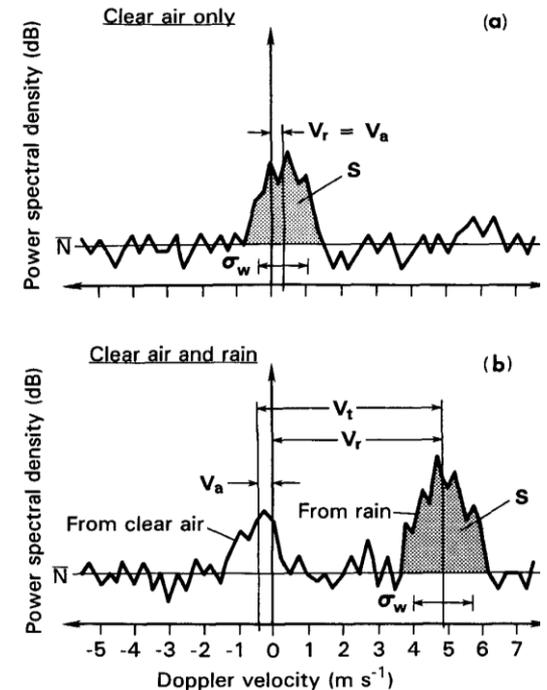
Three Basic Moments:
Mean Doppler Velocity (V_a=W)
Doppler width (σ_w)
Backscatter (dBZ)

Time-Height Cross Section Cloud Views


VOCALS 2008-11-28 day333, Ceilometer Cloud Base
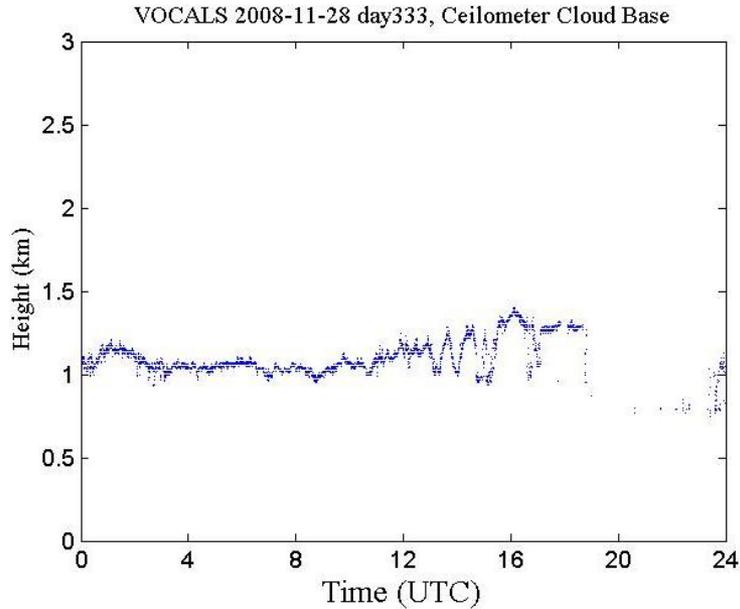
Time series of ceilometer cloudbase height for Nov. 28.


SST VOCALS 2008

VOCALS2008 W-Band' YD 333 Hr 06
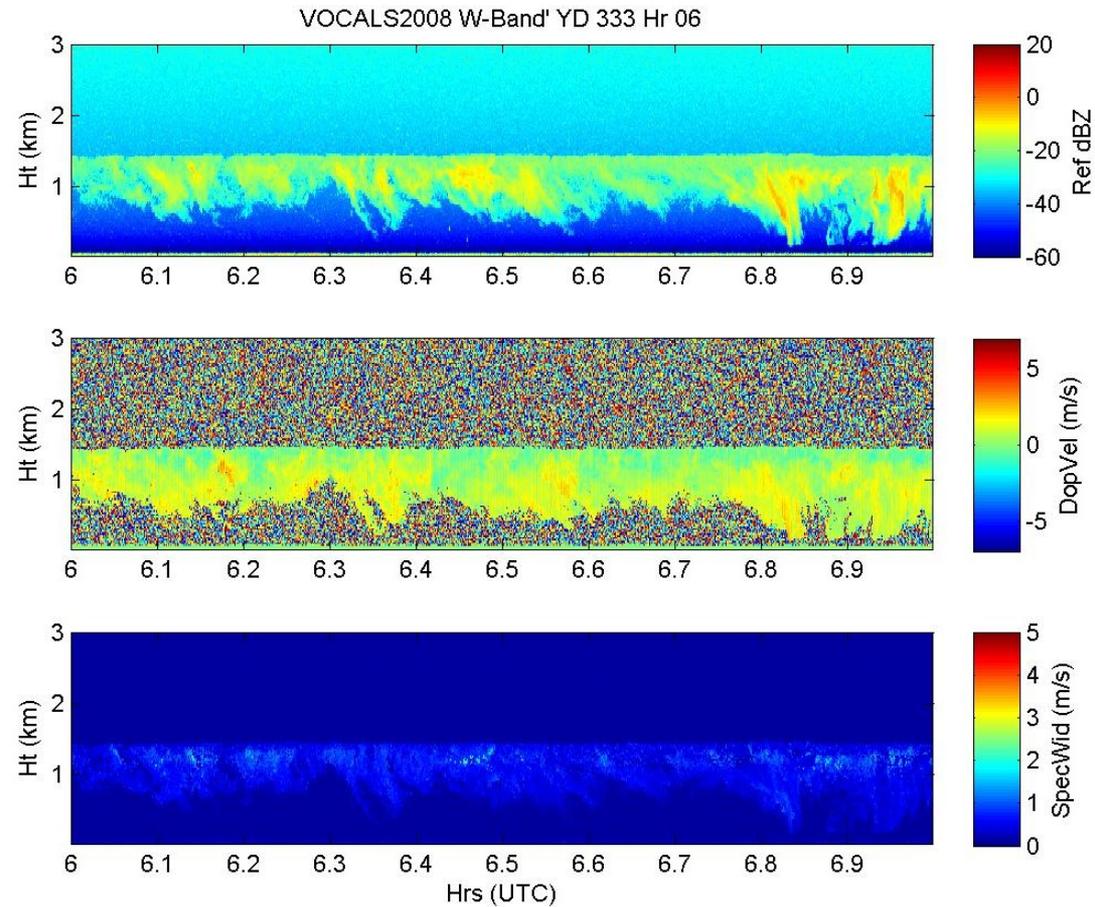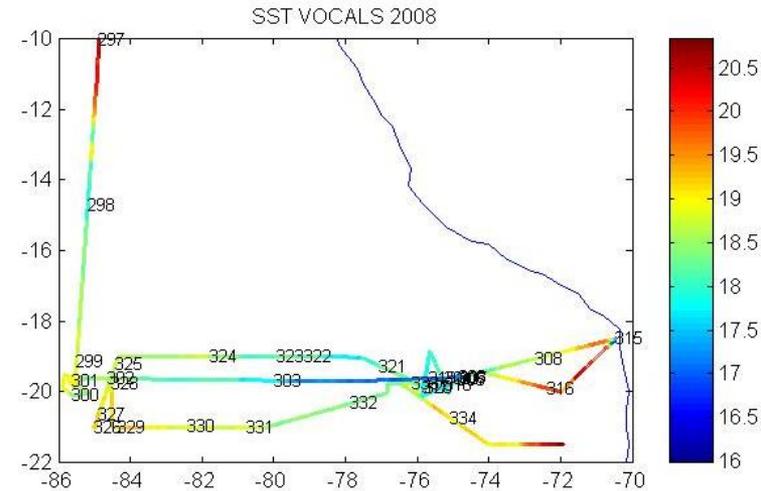
Time-height cross section from **1 hour** of data beginning at 0600 on Nov. 28 (Day 333) from ESRL/PSD W-band cloud radar. The top panel is the radar reflectivity (dBZ); the middle panel is the mean Doppler velocity (m/s, positive down); the bottom panel is the Doppler width (m/s) of the return.

Turbulent Velocity Profile Information

$$W_{air} = W_{meas} - W_{Gravity}(dBZ) - W_{mot}$$
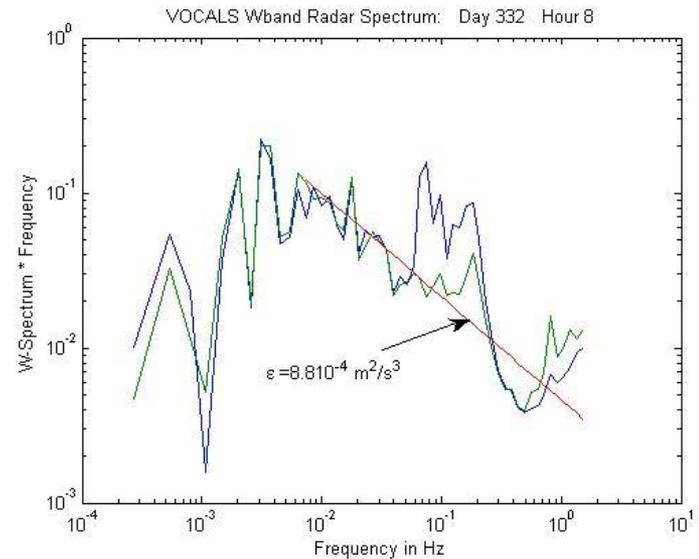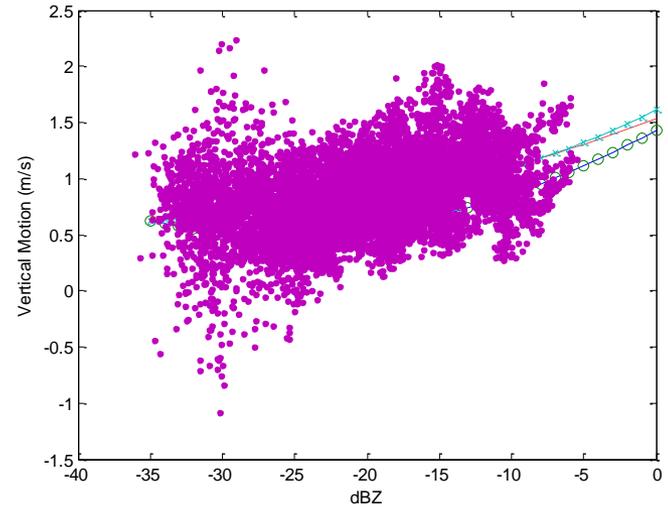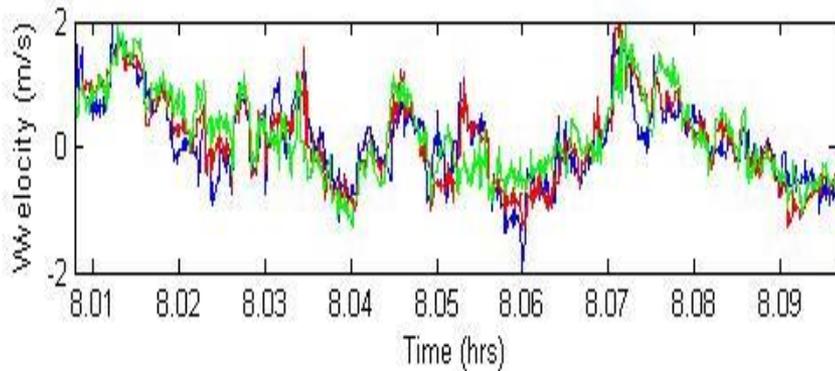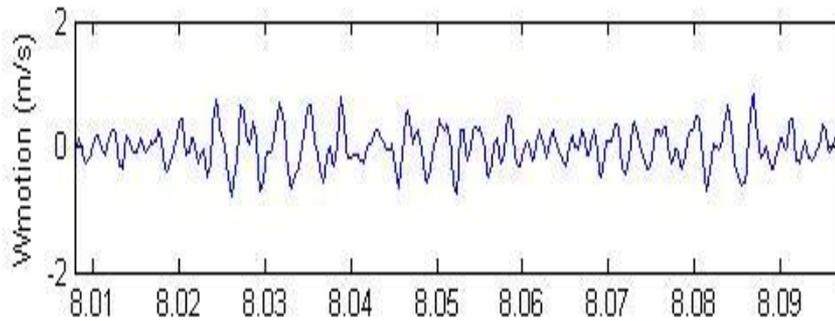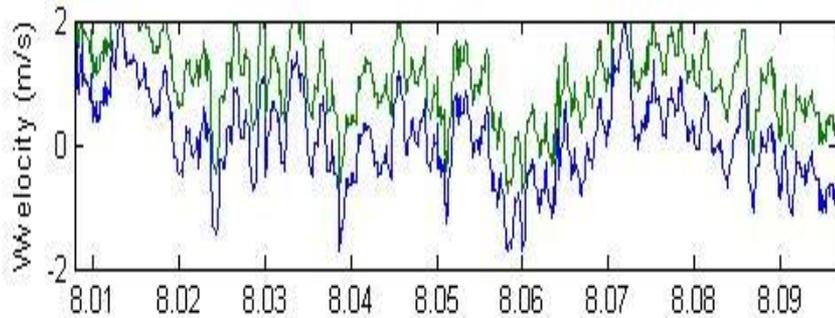
Example cloud/drizzle Effects
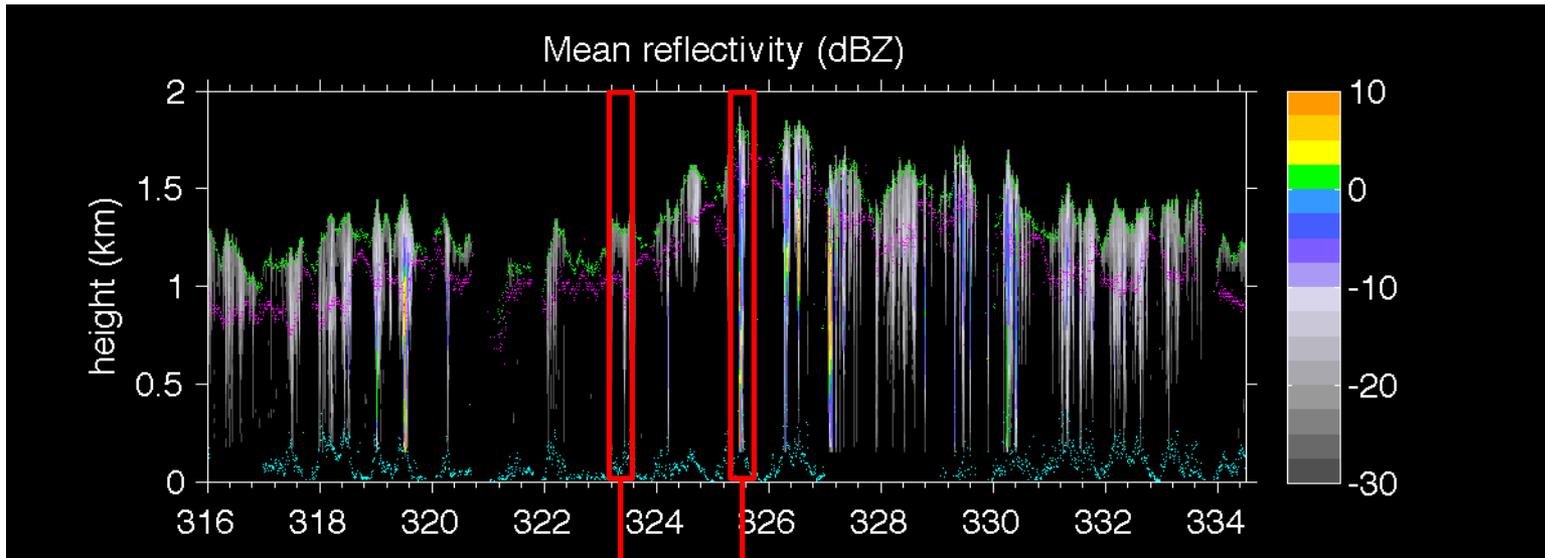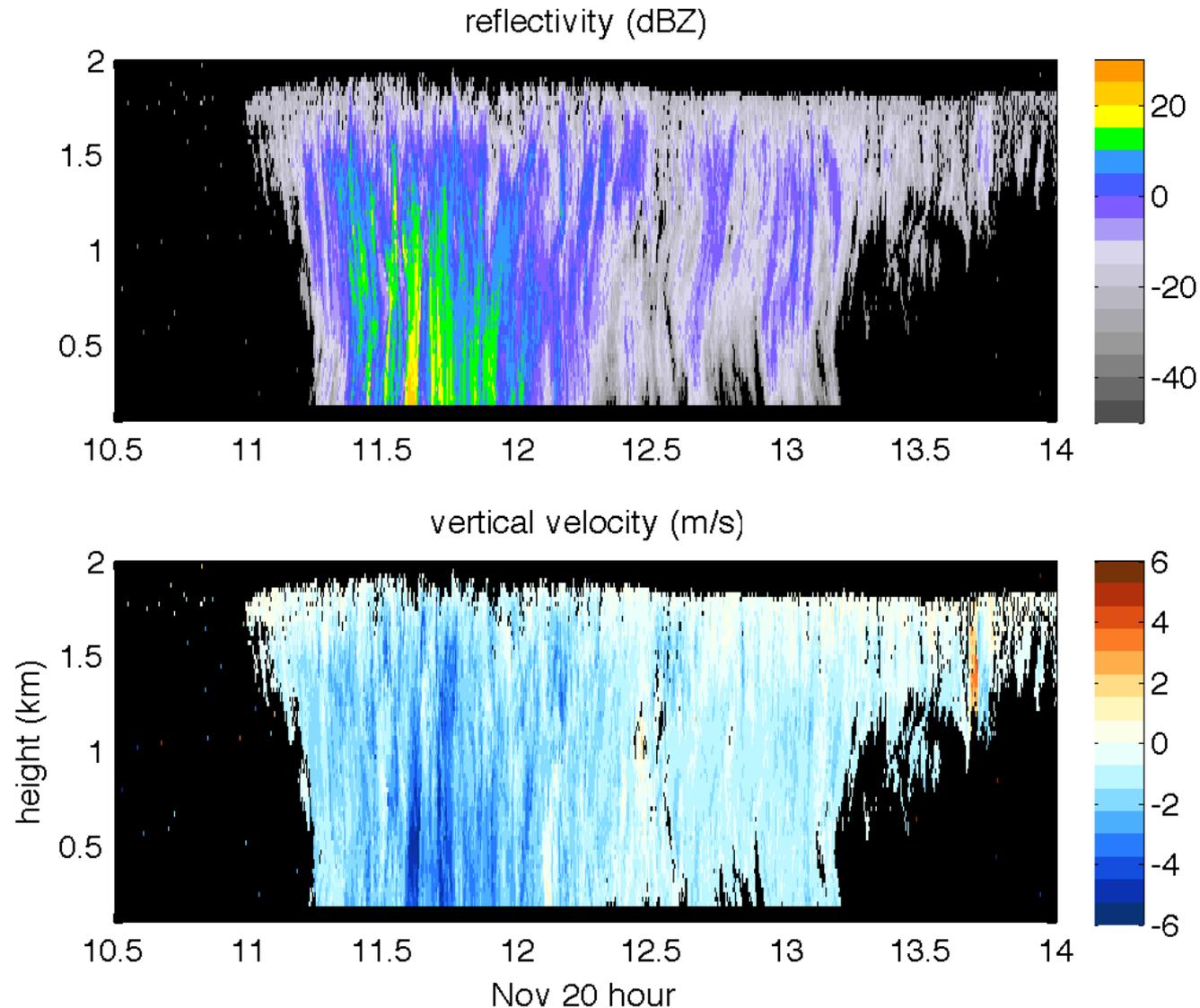
November 18, a nonrainy period
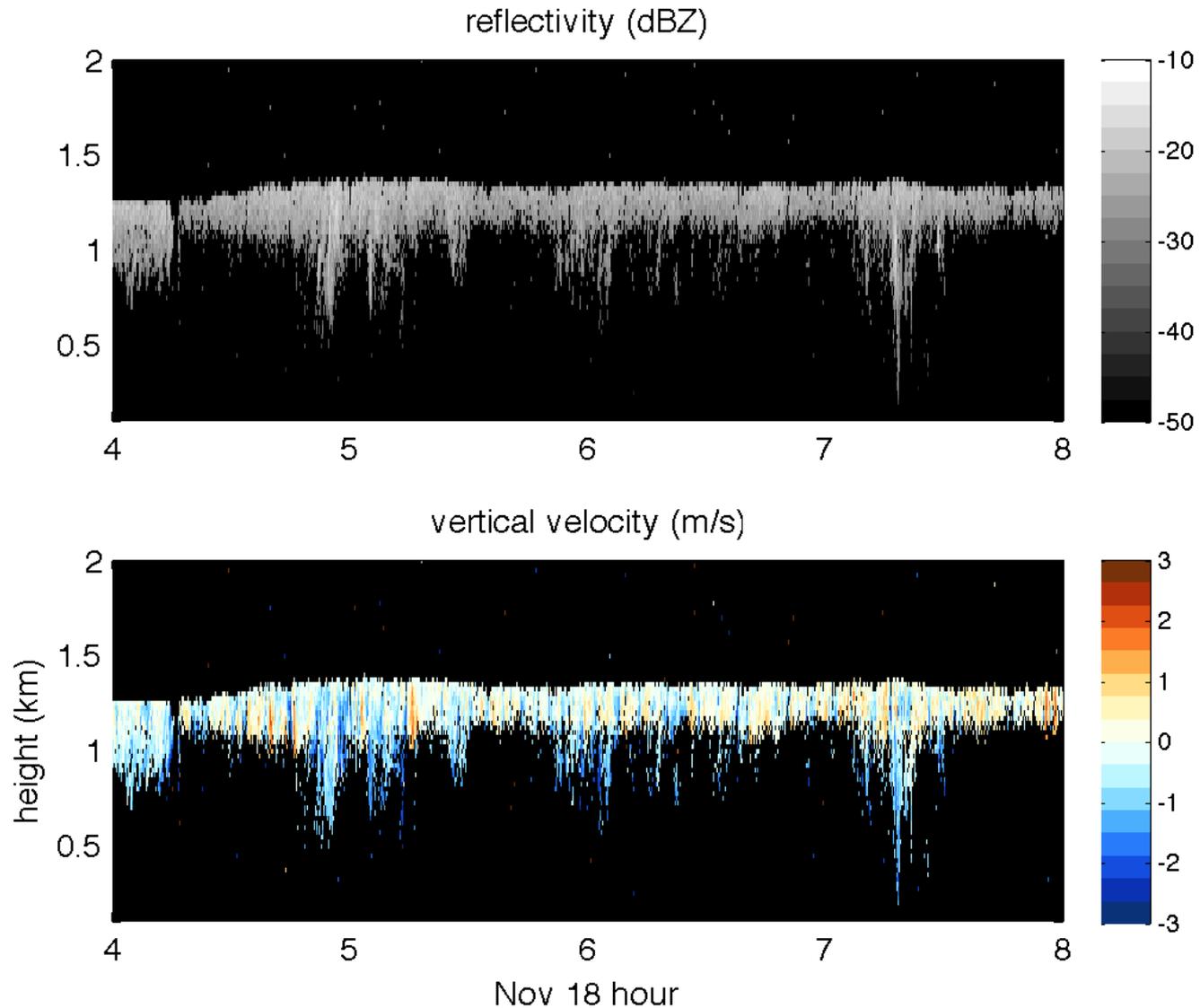
Joint dBZ-Velocity Distributions As Function of Height in the Cloud
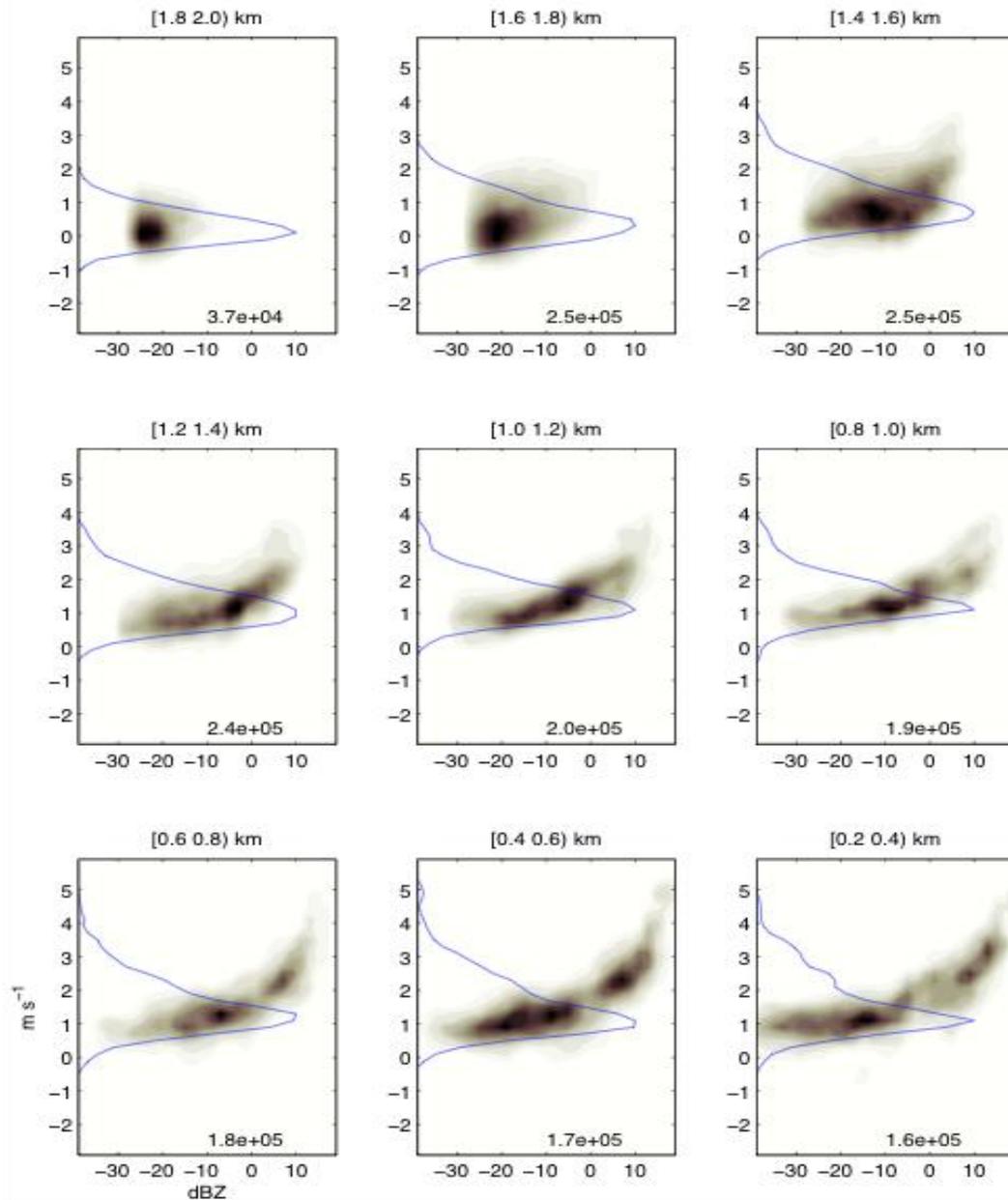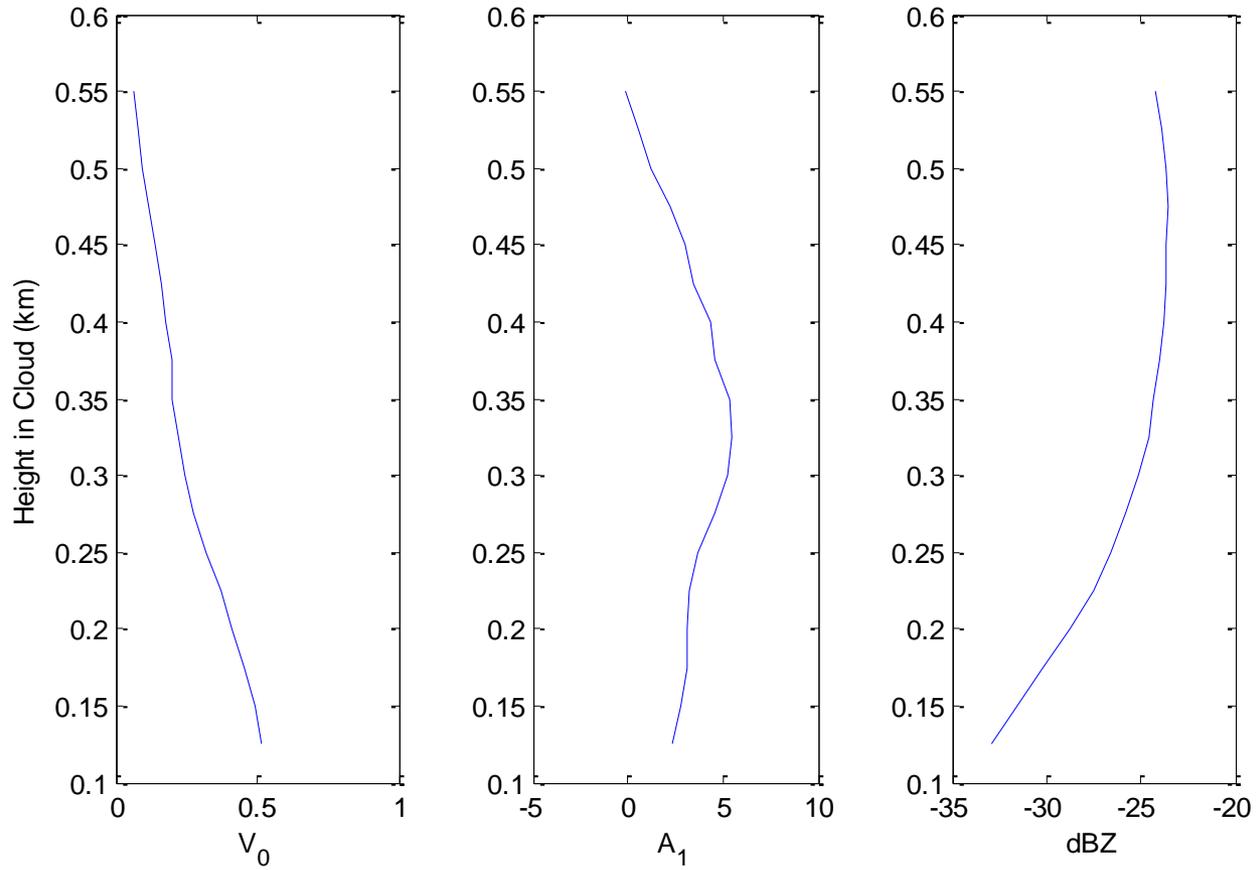## From cloudtop down, 200 m height bins

Zbase=1.0 km
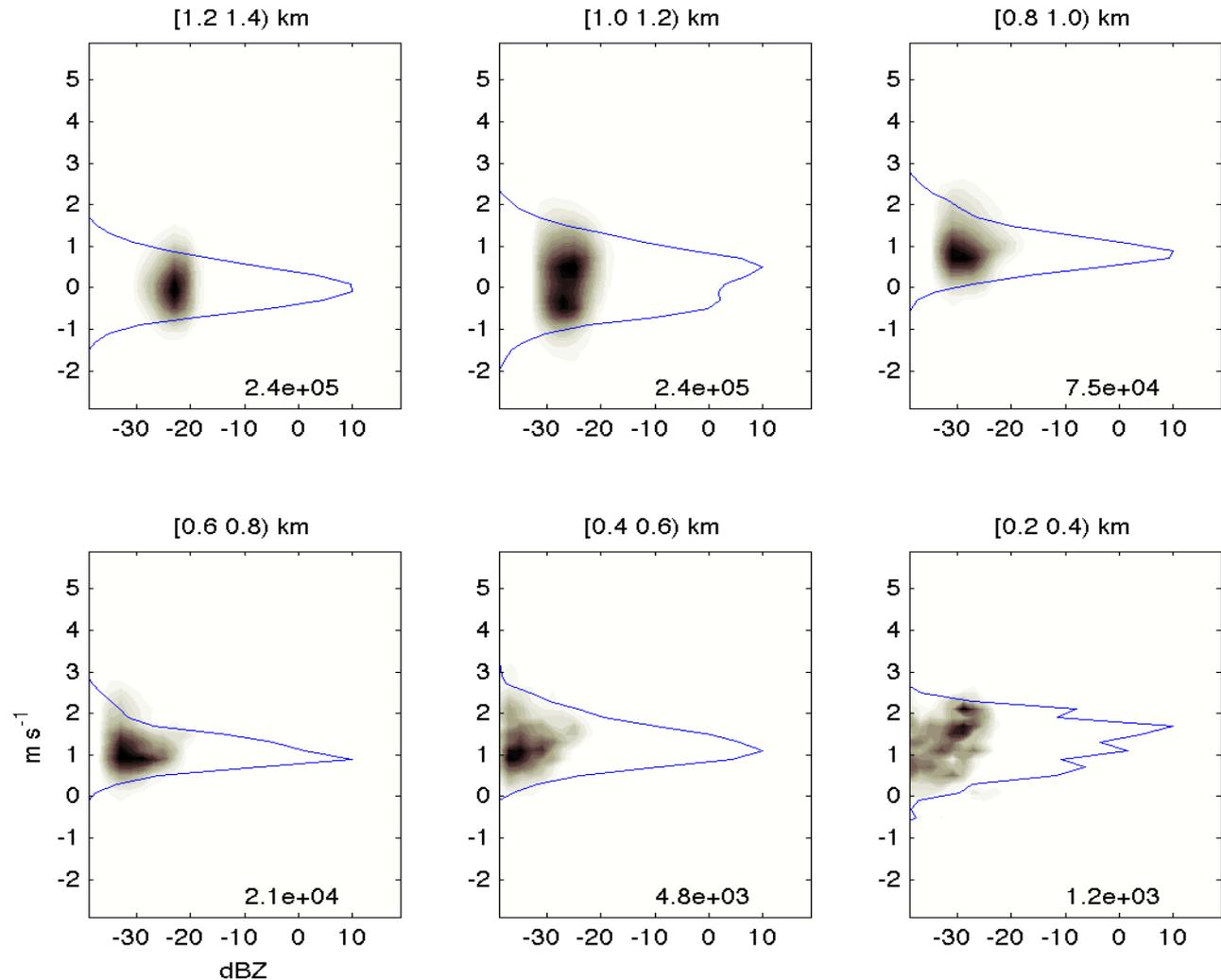
November 20, a rainy period

Joint dBZ-Velocity Distributions As Function of Height in the Cloud
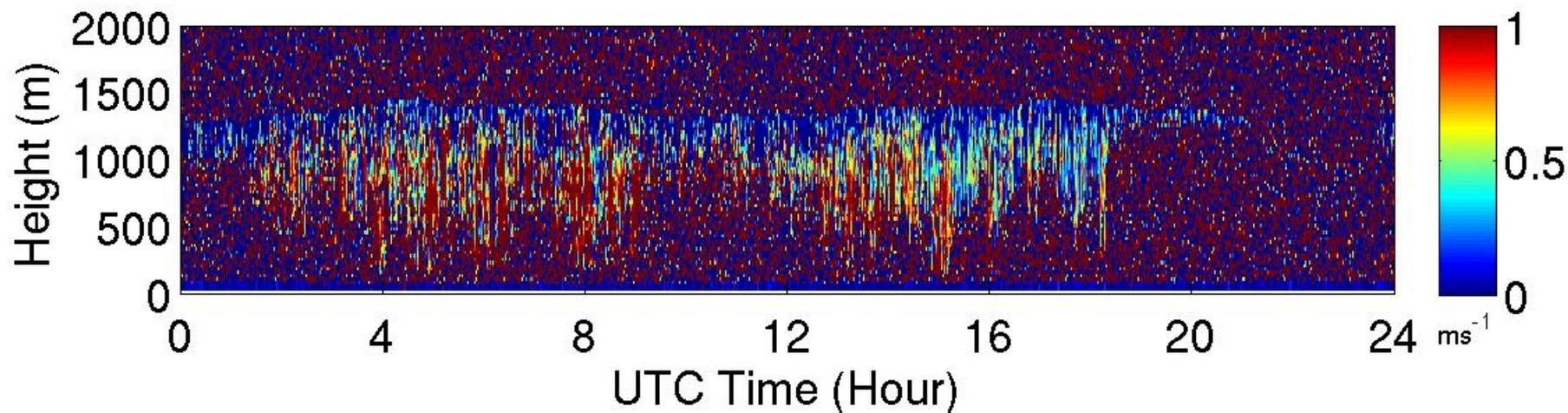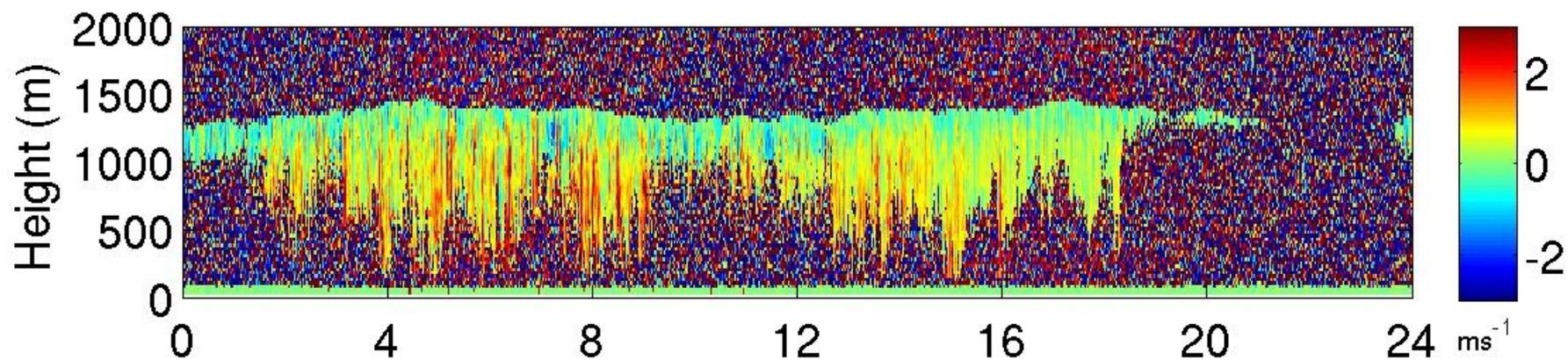## From cloudtop down, 200 m height bins
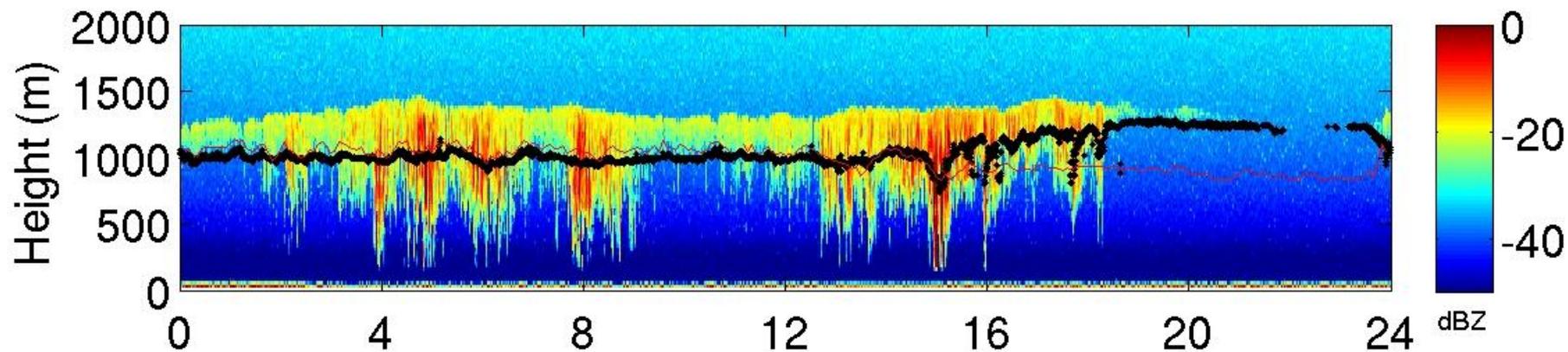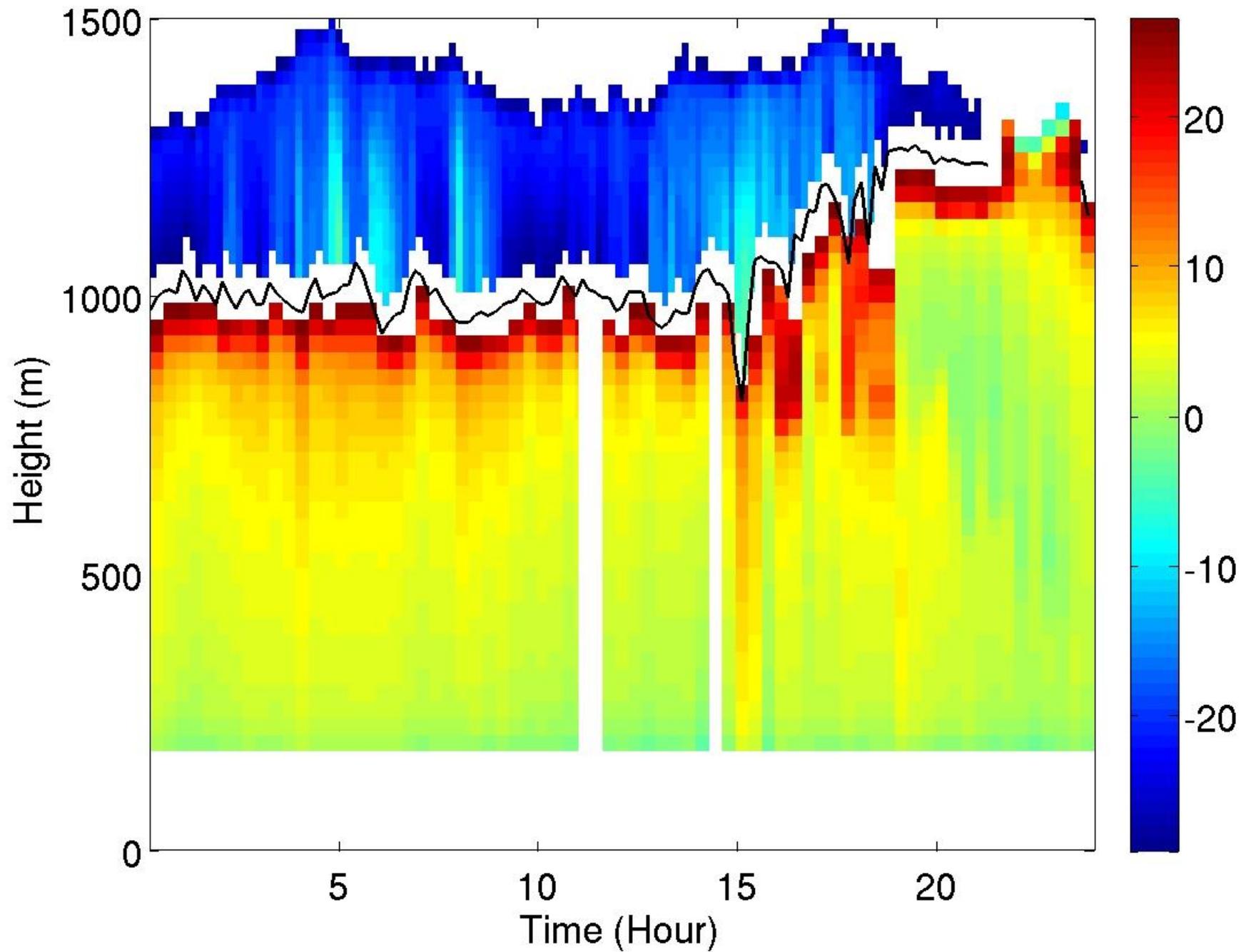
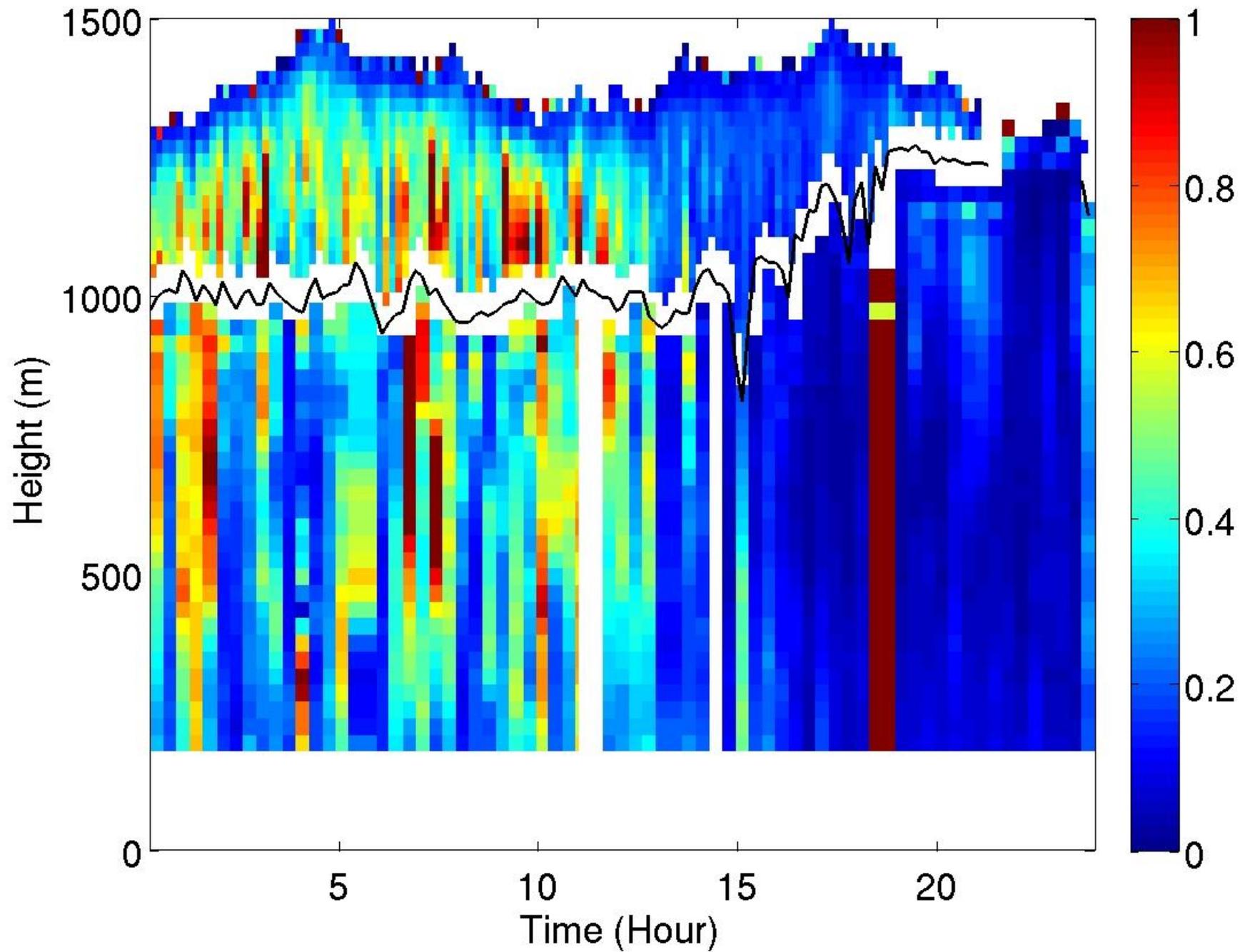Zbase=1.3 km

W=A0+A1*exp(0.0*dBZ)
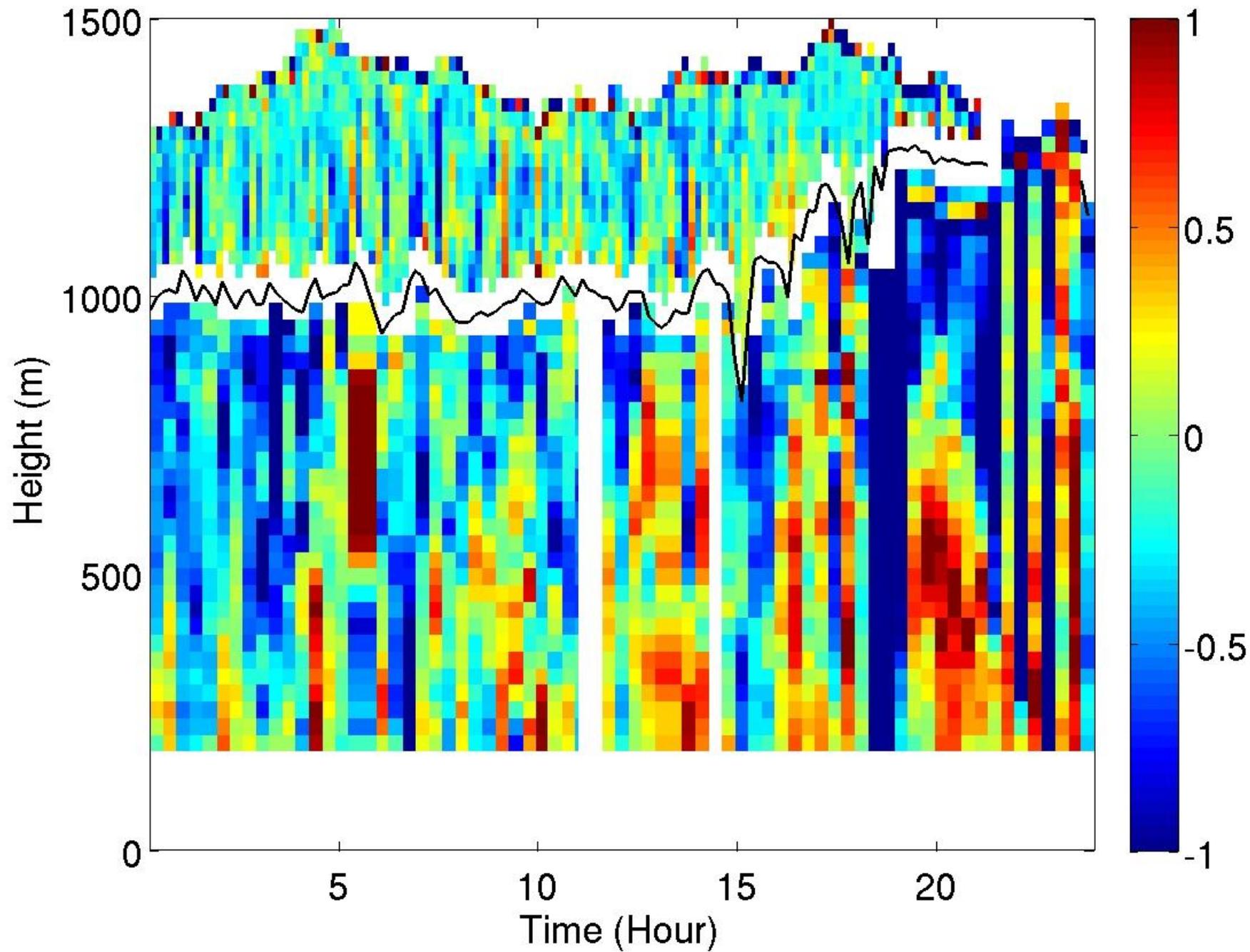
ESRL w-band 20081127

Lidar SNR + radar dBZ

Lidar+radar variance

Lidar+radar skewness
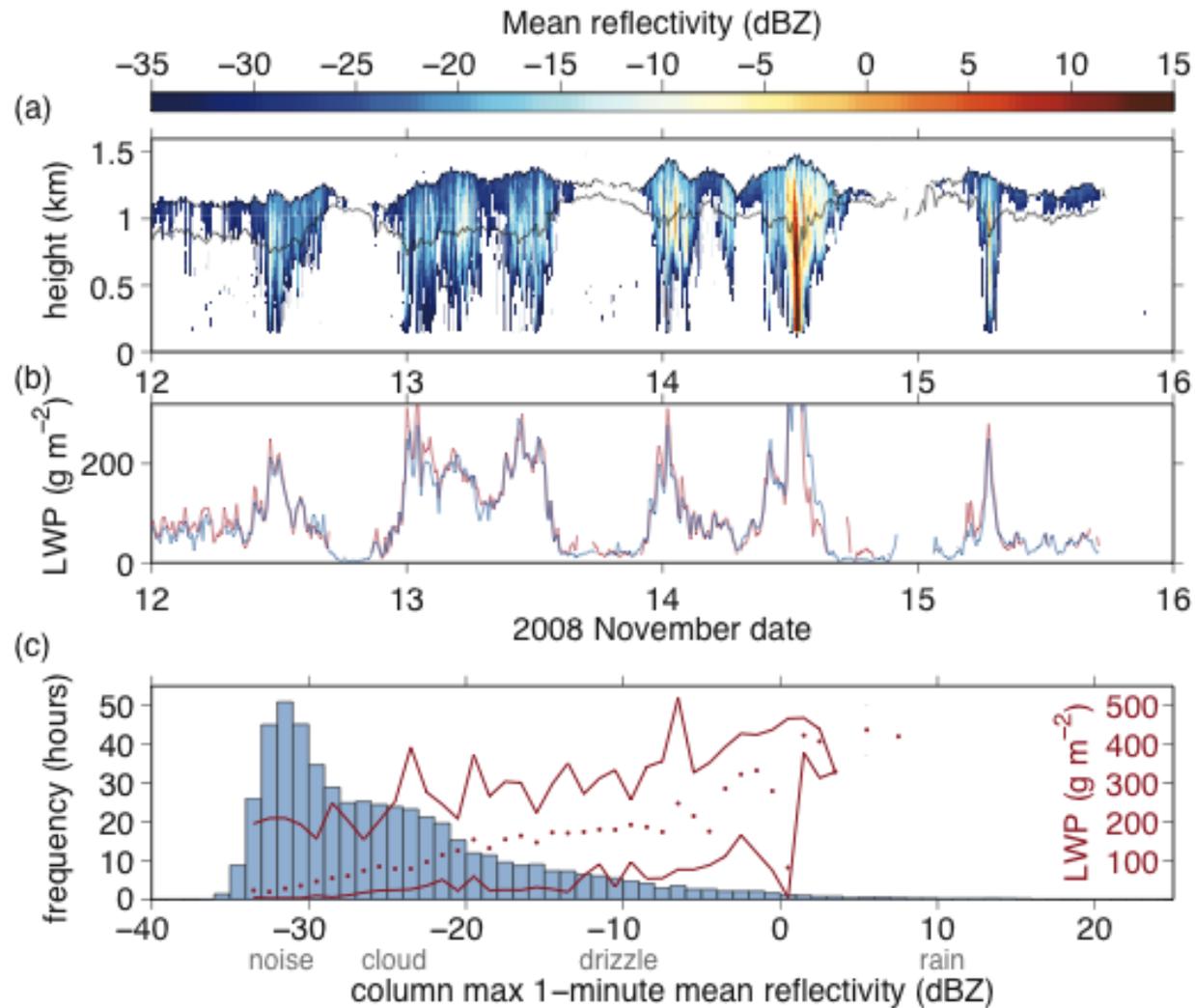
Linking Cloud Microphysics and Liquid Water

Figure. (a) Mean reflectivity from the W-band cloud radar for November 12-15. Thin lines are cloud top height estimated from the radar and cloud base height from the ceilometer. (b) Liquid water path (LWP) from the microwave radiometer (red) and adiabatic LWP from cloud thickness (blue). Bars in (c) show the frequency of occurrence in hours of column **maximum reflectivity** (dBZ) of 1-minute samples for *all 538 hours* of the VOCALS cloud radar record. The median and range of 10-minute LWP (g m⁻², red dots and lines) are binned by column maximum reflectivity.