Atmospheric Influences on New Snowfall Density in the Southern Appalachian Mountains, USA

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ABSTRACT

The natural variability and atmospheric influences on new snowfall density in the southern Appalachian Mountains remain poorly understood, resulting in a significant forecasting challenge. This paper assesses the atmospheric influences on new snowfall density on Poga Mountain (1018 m), NC, from data collected during the 2006-2007 and 2007-2008 snow seasons. Data sources include snowfall and snow water equivalent (SWE) measurements, surface meteorological data (e.g. temperature, humidity, wind, and pressure), upper-air data from special rawinsonde releases, field observations of snow crystal morphology and degree of riming, and data from a vertically-pointing 24.1 GHz radar. Preliminary results indicate that new snowfall density varies considerably during the same event and also among events with similar synoptic conditions, with values ranging from 15 to 328 kg m^{-3}. The mean snowfall density for the two-year study period was 69 kg m^{-3}. The typical cold NW flow event has a new snowfall density of 55 kg m^{-3}. The highest new snowfall densities (> 110 kg m^{-3}) were associated with high surface temperatures and/or the presence of a near-freezing layer. Graupel and heavily rimed snow crystals also contributed to high new snowfall densities during several Miller A cyclones. Surface air temperature is only weakly correlated with new snowfall density.

Keywords: new snowfall density; atmospheric influences; southern Appalachian Mountains

INTRODUCTION

Variations in new snowfall density have a significant influence on new snowfall totals, as the same liquid equivalent precipitation can yield wide differences in actual snowfall. Correctly diagnosing and forecasting new snowfall density remains one of the foremost challenges in improving snowfall forecasts (Judson and Doesken 2000; Roebber et al. 2003; Kay 2006). The natural variability of new snowfall density and the associated atmospheric influences remain poorly understood, particularly in mountainous regions where orographic effects predominate and lower tropospheric meteorological elements exhibit pronounced spatial variability. Measurements of new snowfall density are scarce at best, and non-existent in many regions. Melted gauge-collected precipitation data (e.g. from NWS cooperative observer stations in the U.S.) are often used as a surrogate measure for diagnosing the liquid equivalent of new snowfall. Significant gauge undercatch due to wind effects (e.g. Goodison 1978; Yang et al. 1998; Faasnacht 2004) and rainfall contamination in rain-to-snow transitions render these measurements problematic at best.

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Wind effects, melting, and snow metamorphism create additional challenges to measuring new snowfall accumulation or depth (Doesken and Leffler 2000). Relatively infrequent new snowfall observations, such as the once daily measurements taken by NWS cooperative observer stations, tend to magnify these effects.

This paper assesses the natural variability and atmospheric influences on new snowfall density through ongoing field experiments in the southern Appalachian Mountains. The research is guided by three primary research questions: 1) What are the observed new snowfall densities at the Poga Mountain field site for the 2006-2007 and 2007-2008 snow seasons? 2) How does new snowfall density vary by low-level wind direction and surface temperature? 3) What is the relationship between selected atmospheric variables (e.g. surface temperature, moist layer temperature and thickness, 850 hPa wind speed) and new snowfall density?

DATA AND METHODS

Snowfall and snow water equivalent (SWE) measurements were taken at 0000 UTC, 1200 UTC, and 1800 UTC during snow events at 1018 m on Poga Mountain, NC (Fig. 1). All new snowfall and SWE measurements were taken on a thin sheet of plexiglass in the back of an open-top cattle trailer to minimize blowing and drifting effects. A 10-cm diameter precipitation gauge was used to extract core samples, which were then melted and recorded using standard measurement techniques developed in support of the Community Collaborative Rain, Hail, and Snow (CoCoRaHS) Network (Doesken 2007). Surface meteorological data were obtained using a portable station at 1137 m near the top of Poga Mountain (Fig. 2a), where wind measurements were more exposed and thus more representative of the large-scale flow. A vertically-pointing 24.1 GHz METEK Micro Rain Radar (MRR) (measures radar reflectivity and Doppler velocity, e.g. Peters et al. 2002), Parsivel disdrometer (Löffler-Mang and Joss 2000; Löffler-Mang and Blahak 2001; Yuter et al. 2006) and Pluvio weighing precipitation gauge provided additional data at 1018 m (Fig. 2b). During the 2007-2008 snow season, the research team released rawinsondes from 1018 m every three hours during snow events to obtain additional data on the vertical profiles of temperature, moisture, and wind (Fig. 2c). Observations of snow particle habit and degree of riming were also made at 1018 m during snow events using a stereomicroscope.

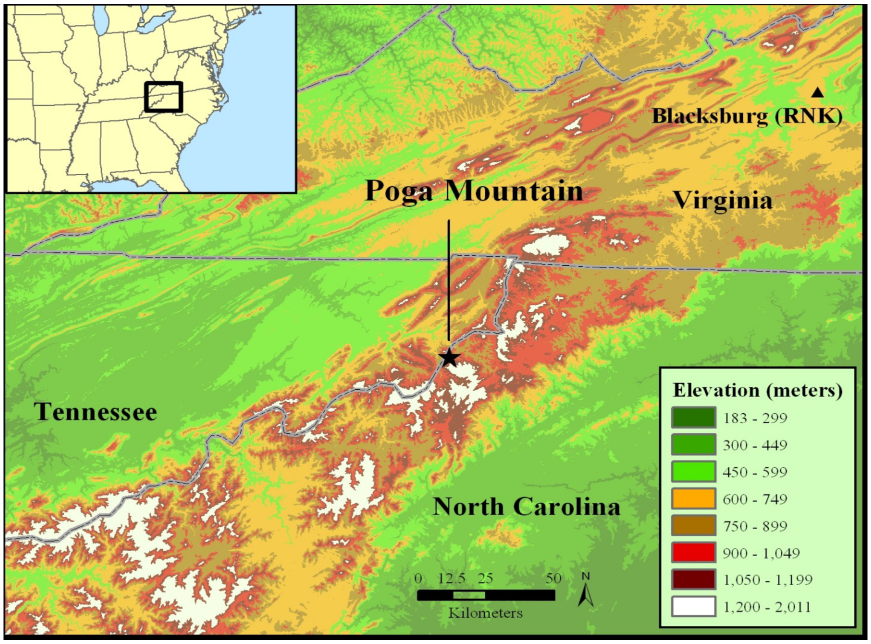

Figure 1. Location of field site on Poga Mountain, NC.

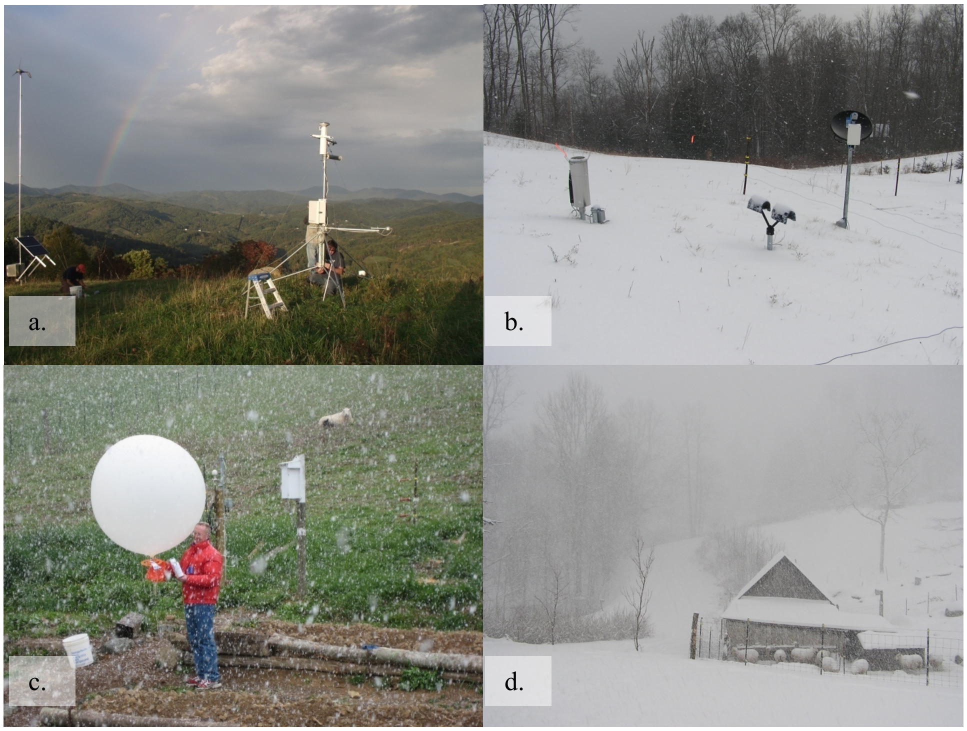

Figure 2. Instrumentation on Poga Mountain: a) portable meteorological station near the crest at 1137 m, b) Pluvio weighing precipitation gauge, Parsivel disdrometer, and vertically-pointing Micro Rain Radar (l to r) at 1018 m, c) D. Miller preparing rawinsonde during 14 Apr 2008 snow event, d) view SSW from field site at 1018 m during 12 Feb 2006 snow event.

RESULTS

Mean annual snowfall for the two-year study period was 74.5 cm, which was considerably below the 115.0 cm annual mean and well below the 168.0 cm that accumulated during the 2003-2004 snow season. Most of the snowfall events (88%) were defined as northwest flow snowfall (NWFS, e.g. Perry and Konrad 2006; Perry et al. 2007) on the basis of low-level NW (270-360 degrees) flow during the period of heaviest precipitation. NWFS contributed 93% of the total snowfall and 84% of the total SWE observed during the period. The preferred wind direction ranged between 270 and 315 degrees, with a handful of events between 90 and 150 degrees (Fig. 3a). The mean new snowfall density was 69 kg m^{-3}, with 15 events (56%) exhibiting new snowfall densities between 25 and 75 kg m^{-3}, and only 8 events (30%) greater than 100 kg m^{-3} (Fig. 3b). Snow density ranged from a minimum of 15 kg m^{-3} to a maximum of 325 kg m^{-3}, with a modal value of 50 kg m^{-3}. In general, the cold (< -2 °C) NWFS events exhibited the lowest snow densities, with a mean value of 55 kg m^{-3}. Warm (> -2 °C) NWFS events and the small sample (n = 3) of other synoptic types had the highest new snowfall densities, with a mean value of 149 kg m^{-3} (Fig. 4a). Of the surface meteorological variables, temperature is weakly correlated (r = 0.67) with new snowfall density (Fig. 4b).

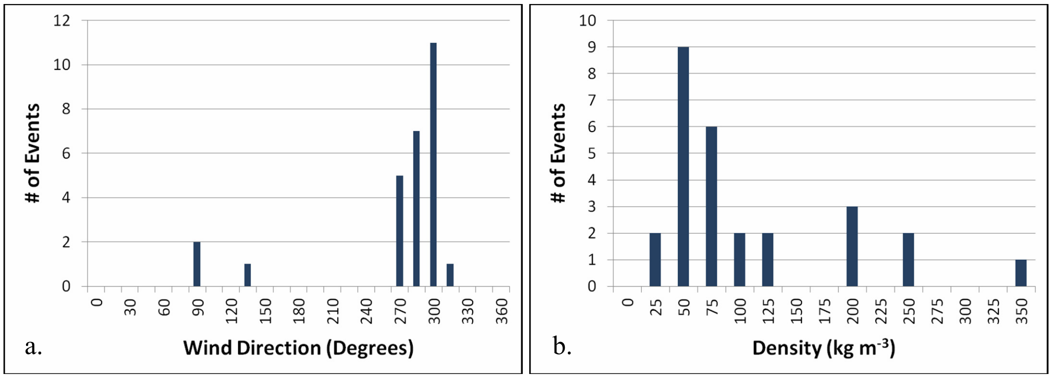

Figure 3. Number of snow events by a) wind direction and b) snow density.

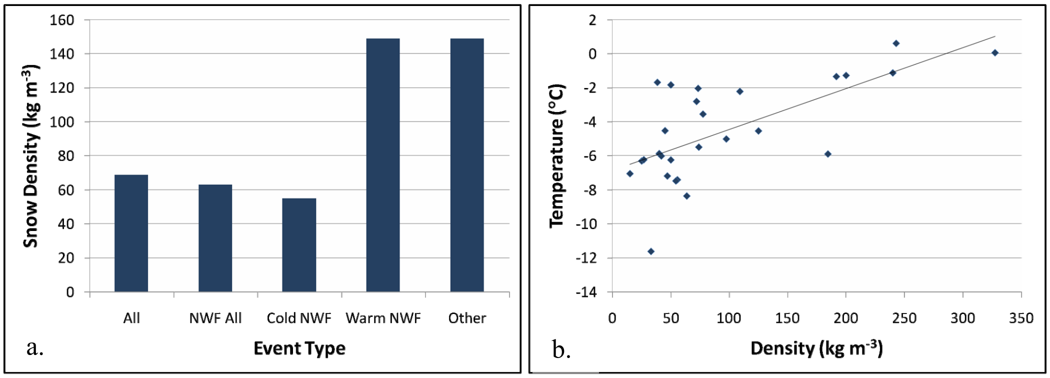

Figure 4. a) New snowfall density by event type and b) new snowfall density vs. surface temperature.

Data from five snowfall events over the past two snow seasons are useful in illustrating the variability of new snowfall density by synoptic patterns and prevailing wind direction, vertical structure of temperature and precipitation, and surface meteorological parameters (Table 1). On 15-16 Apr 2007, a Miller A cyclone (e.g. Miller 1946) tracked NNE from the Gulf of Mexico, bringing abundant moisture into the southern Appalachian Mountains (Fig. 5). As cold air began to wrap around the western edge of the storm on low-level northwest winds, rain changed to snow at 1800 UTC and began to accumulate by 1900 UTC on 15 Apr. At 2300 UTC, the radar echo tops became considerably shallower. New snowfall density averaged 109 kg m^{-3} for the event, including a period of graupel just prior to 0200 UTC that contributed to much higher new snowfall densities during the latter portion of the event. The 1-3 Jan 2008 event is a good example of NWFS (Fig. 6), which included very low surface and moist layer temperatures, and some instability below 700 hPa. New snowfall density was very low, averaging only 33 kg m^{-3} for the entire event, while radar echo tops became quite low, particular towards the end. On 17-18 Jan 2008, a Miller A cyclone tracked ENE out of the Gulf of Mexico (Fig. 7), bringing a transition from virga to snow, sleet, freezing rain, and rain. The layer between 850 and 700 hPa stayed nearly isothermal just below 0 °C until 1200 UTC 18 Jan, resulting in relatively high new snowfall densities of 138 kg m^{-3} before the transition to sleet and freezing rain. 27-28 Feb 2008 represented a prolonged NWFS event (Fig. 8) with low surface and moist layer temperatures and low echo tops. New snowfall density averaged 47 kg m^{-3} for the event, with a transition to slightly lower values towards the end. A weak Ohio Valley disturbance on 29 Feb to 1 Mar 2008 (Fig. 9) produced a short period of heavy snowfall in association with surface temperatures slightly above 0 °C and a near-freezing isothermal layer between the surface and 750 hPa. New snowfall density averaged 328 kg m^{-3} for the event, increasing during the latter stages as surface and moist layer temperatures warmed.

Table 1. Storm summaries for selected snowfall events during the study period. Meteorological data are two-hour averages during the period of heaviest precipitation.

Date	Dur-ation	New Snow	SWE	Den-sity	Snow: Liquid	Temp	RH	Wind Spd	Wind Dir
	Hrs	*cm*	*mm*	*kg m^{-3}*	*Ratio*	*°C*	*%*	*m s^{-1}*	*Degrees*
15-16 Apr 2007	11	11.2	12.2	109	9.2	-2.2	96.0	5.4	304
1-3 Jan 2008	42	10.2	3.4	33	30.3	-11.6	83.3	6.2	297
17 Jan 2008	14	4.6	8.4	184	5.4	-5.9	89.9	5.3	96
26-28 Feb 2008	44	21.1	9.9	47	21.3	-7.2	91.4	5.3	295
29 Feb 2008	13	1.0	3.3	328	3.1	0.1	92.3	1.5	138

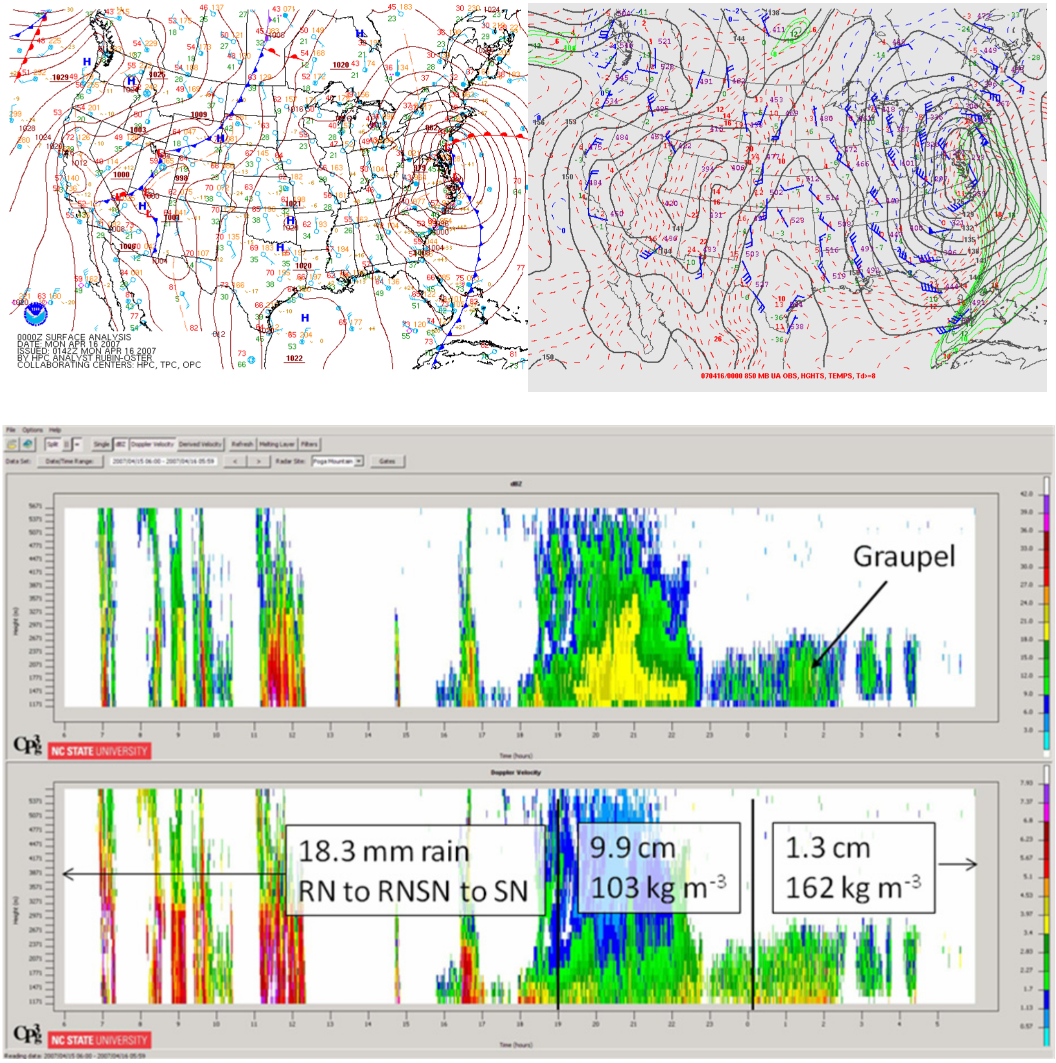

Figure 5. Surface and 850 hPa maps for 0000 UTC 16 Apr 2007 (top) and vertically pointing radar image for 15-16 Apr 2007 (bottom). Storm total: 11.2 cm, 109 kg m^{-3}.

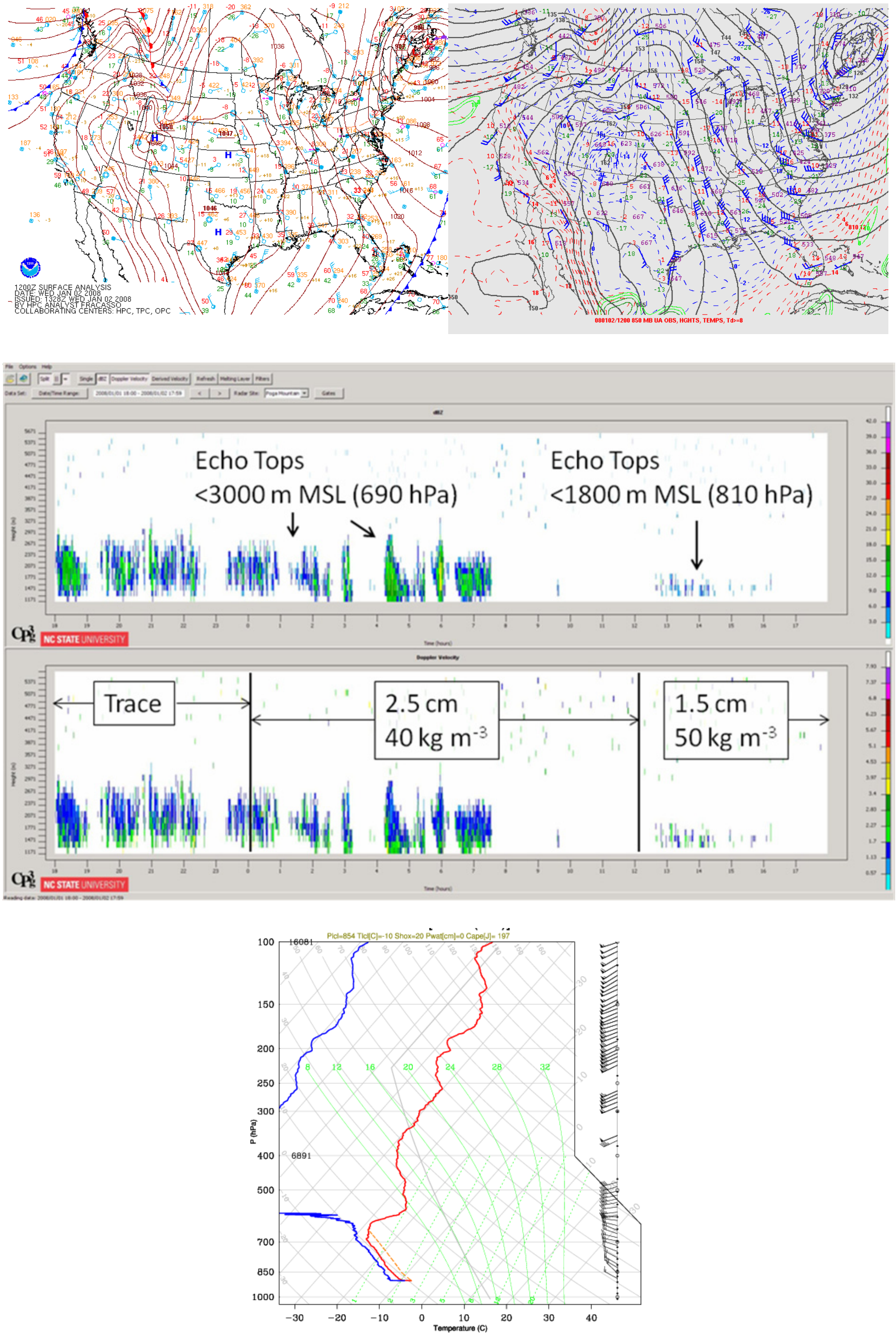

Figure 6. Surface and 850 hPa maps for 1200 UTC 2 Jan 2008 (top), vertically pointing radar image for 1-3 Jan 2008 (middle), and rawinsonde plot for 0600 UTC 2 Jan 2008 (bottom). Storm total: 10.2 cm, 33 kg m^{-3}.

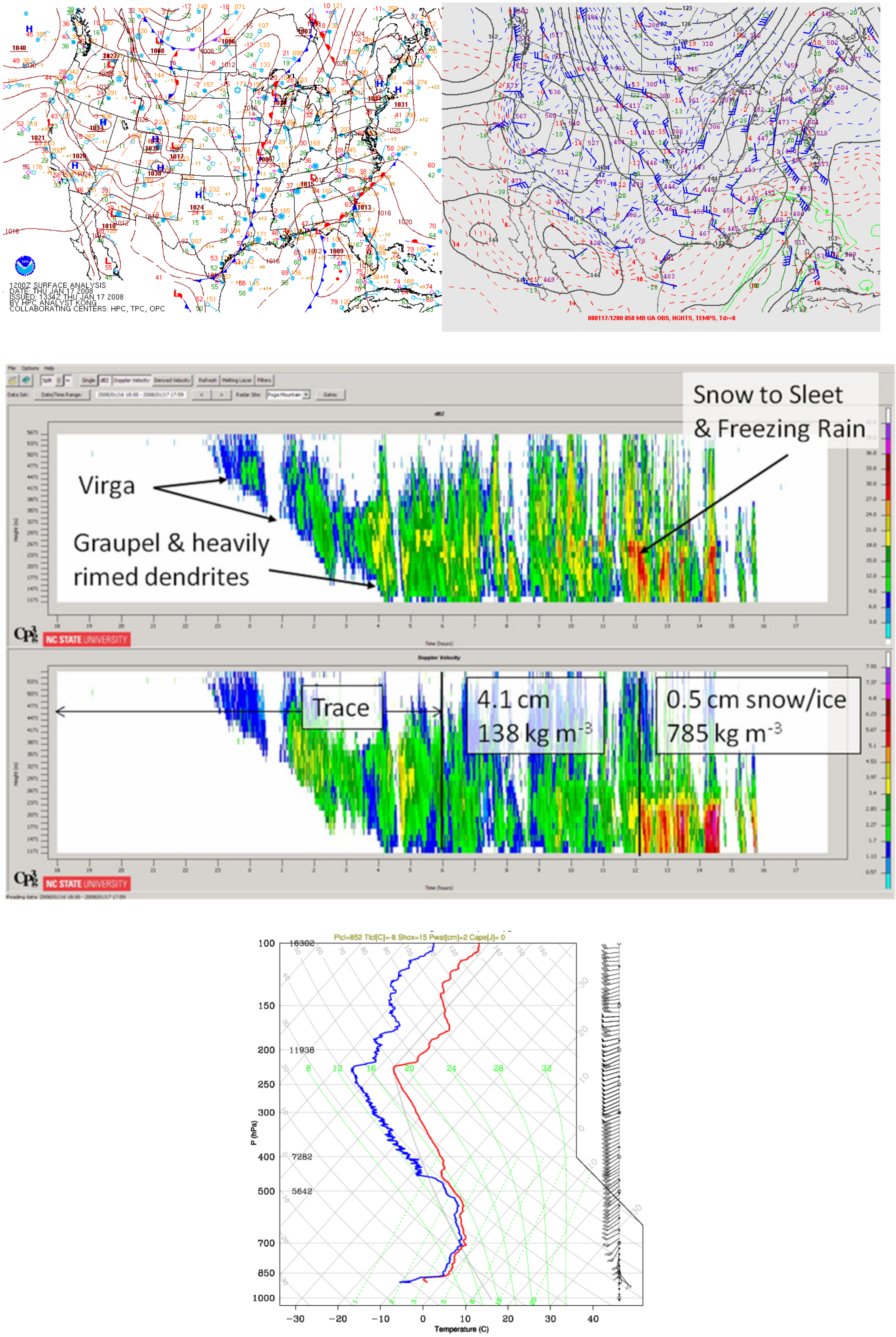

Figure 7. Surface and 850 hPa maps for 1200 UTC 17 Jan 2008 (top), vertically pointing radar image for 16-17 Jan 2008 (middle), and rawinsonde plot for 0600 UTC 17 Jan 2008 (bottom). Storm total: 4.6 cm, 184 kg m^{-3}.

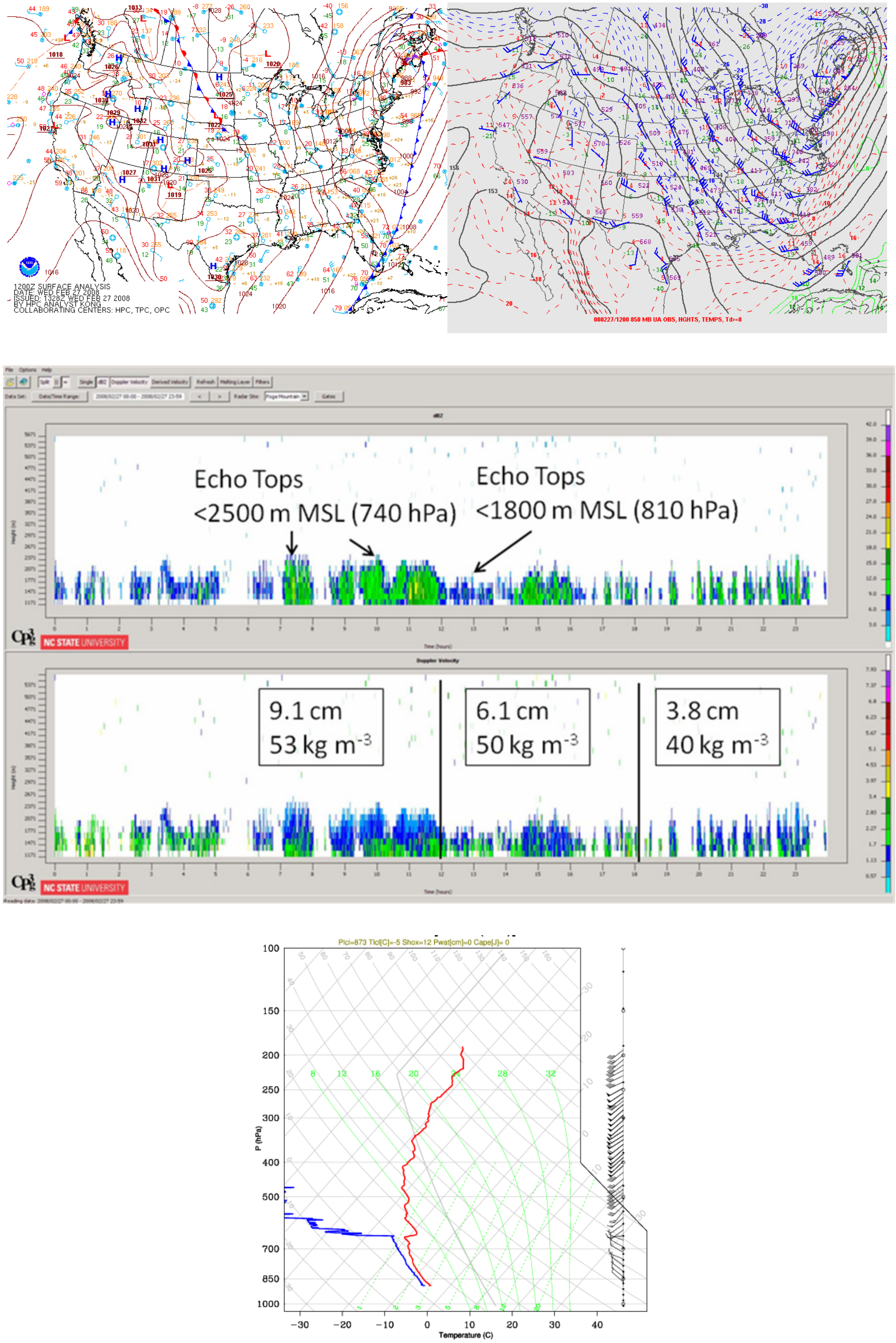

Figure 8. Surface and 850 hPa maps for 1200 UTC 27 Feb 2008 (top), vertically pointing radar image for 27-28 Feb 2008 (middle), and rawinsonde plot for 0900 UTC 27 Feb 2008 (bottom). Storm total: 21.1 cm, 47 kg m^{-3}.

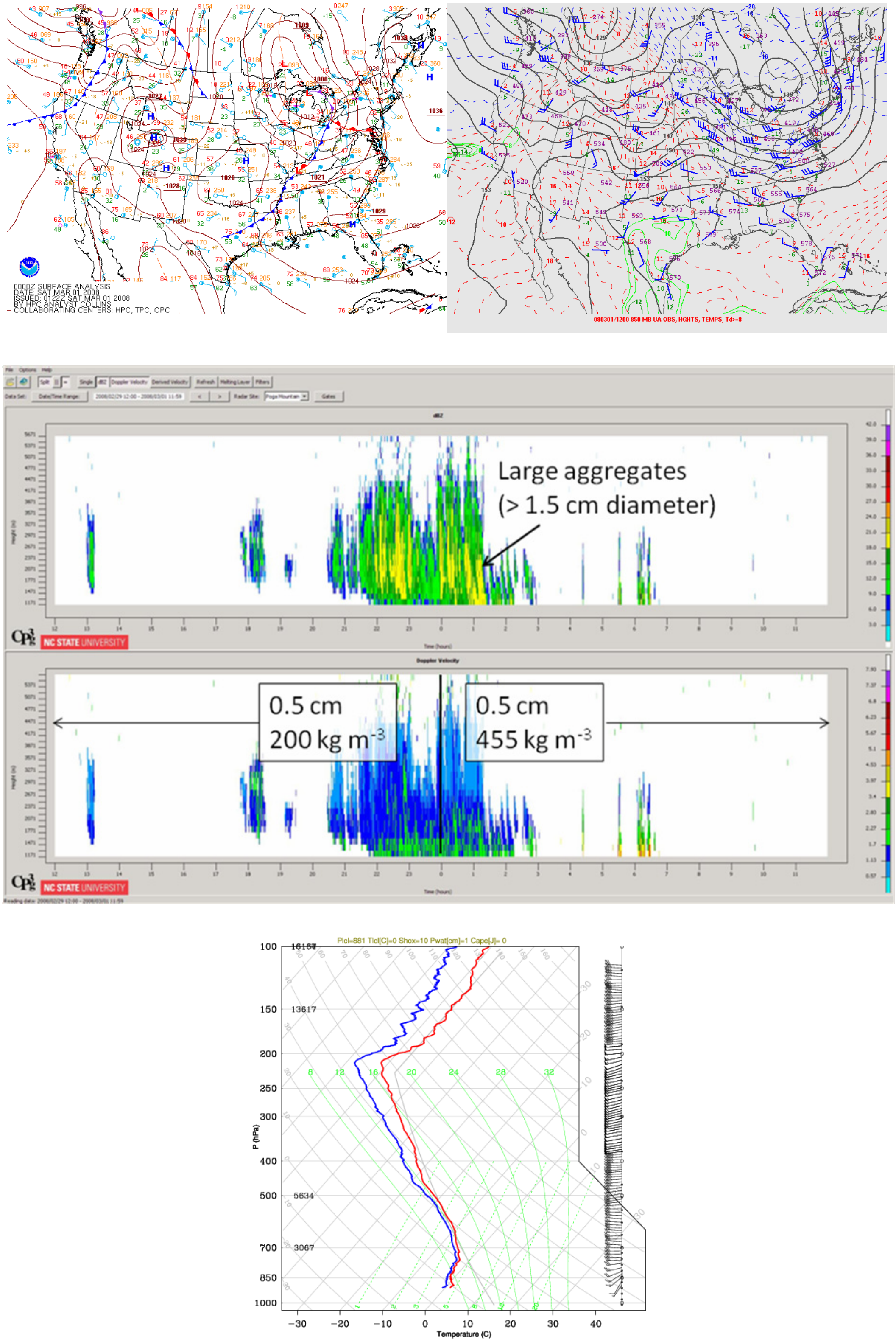

Figure 9. Surface and 850 hPa maps for 0000 UTC 1 Mar 2008 (top), vertically pointing radar image for 29 Feb to 1 Mar 2008 (middle), and rawinsonde plot for 0000 UTC 1 Mar 2008 (bottom). Storm total: 1.0 cm, 328 kg m^{-3}.

SUMMARY AND CONCLUSIONS

Snowfall at the Poga Mountain site during the two-year study period was most commonly low density, with a mean value of 69 kg m^{-3} and a modal value of 50 kg m^{-3}. New snowfall densities varied widely among individual events, ranging from 15 to 328 kg m^{-3}. Most of the snowfall (93%) and SWE (84%) occurred in association with low-level NW flow at event maturation. The lowest new snowfall densities (< 40 kg m^{-3}) were all associated with low-level NW flow, low surface temperatures, and a shallow moist layer. The highest new snowfall densities (> 110 kg m^{-3}) were associated with high surface temperatures and/or the presence of a near-freezing layer in the lower troposphere. Graupel and heavily rimed snow crystals also contributed to high new snowfall densities at times. Surface air temperature was weakly correlated with new snowfall density, with a correlation coefficient of 0.67. The results of this study suggest that new snowfall densities exhibit pronounced variability in the southern Appalachian Mountains. Surface and moist layer temperatures, echo top heights, and synoptic patterns all appear to influence new snowfall density, although additional research is needed to investigate the associated physical processes and resulting spatial patterns.

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