17.5 Applying local research to National Weather Service operations: Forecasting heavy mountain snowfalls in Vermont and Northern New York

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1. INTRODUCTION

Heavy snowfalls, greater than 6 inches in 12 hours, that are confined mainly to the Green Mountains of Vermont and the Adirondacks of northern New York (Fig.1) have presented a local forecasting challenge to the National Weather Service (NWS) forecasters in Burlington, Vermont (BTV). NWS BTV assumed long-fused winter weather warning and zone forecast responsibilities in May 1999 and was faced with its first season of winter weather forecasting in the winter of 1999-2000. The purpose of this paper is to show how the results of a local applied research project to understand these heavy mountain snowfalls are used by NWS forecasters to successfully forecast a heavy snowfall event. In the next section, data and methodology are examined. In section 3, previous research on heavy mountain snowfalls in northern NY and VT are examined. In section 4 the results of the research are applied to a heavy snowfall case that occurred on 13-14 November 2003 and the improvement in warning verification scores are examined. Finally, a summary of the findings are presented.

2. DATA AND METHODOLOGY

NWS BTV winter storm verification statistics are obtained for the three heavy mountain snowfall events of 15-16 November 1999, 2-3 March 2000, and 13-14 November 2003. Forecast zone-based Probability of Detection (POD), False Alarm Ratio (FAR), and warning lead time (LT) are computed for each event.

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Snowfall data for 13-14 November 2003 were obtained from NWS cooperative observers and BTV weather spotters.

To examine critical forecast parameters for heavy mountain snows, Advanced Weather Interactive Processing System (AWIPS) forecast procedures were developed to display the 12-km horizontal resolution ETA model data from NOAA's National Centers for Environmental Prediction (NCEP) and a 5-km horizontal resolution workstation version of the ETA model (WSETA) run operationally 4 times a day at BTV.

3. PREVIOUS RESEARCH

St. Jean and Sisson (2004) examined two cases, 15-16 November 1999 and 2-3 March 2000, both with similar synoptic patterns that yielded different results. In the November 1999 case, a heavy snowfall occurred in the Green and Adirondack mountains that was not forecast by the operational numerical weather prediction (NWP) models. Over a foot of snow fell in many mountain locations and only a trace of snow at BTV, located in the Champlain Valley. Forecast zone-based winter storm warning verification statistics are show in Table 1. Verification of the NWS BTV warnings for 15-16 November 1999 yielded a POD of 0.67, FAR of 0.20, and LT of 10 hours.

At that time, some informal efforts were made to identify upper level and surface patterns that led to the heavy snow fall event. For the March 2000 case, Winter Storm Warnings were issued for the Green and Adirondack mountains in anticipation of the event. The event did produce snowfall of 1 to as much as 4 inches, but did not reach warning criteria of more than 6 inches in 12 hours. For this event the POD was 0.00 and FAR was 1.00 with no lead time (Table 1.).

These two events were hypothesized to be largely driven by, moist northwesterly lower tropospheric flow from the surface to ridgetop level (near 850 hPa), that was largely orthogonal to the mountains resulting in heavy snowfall over the higher terrain. This northwesterly flow was thought to be a result of surface low pressure center and upper level cut-off low to the east of the region. It was evident by the challenge of accurately forecasting these two events, that local research was needed to develop the knowledge and tools necessary to forecast events of this type in the future.

In 2001, NWS BTV in association with the University at Albany/SUNY (UA) and other NWS offices, through the Collaborative Science, Technology, and Applied Research Program (CSTAR), began a multi-faceted, multi-year collaborative research project on a wide variety of operational forecast challenges in the northeastern United States. Specifically, the NWS BTV collaborated with UA on the problem of forecasting cut-off cyclones and cases of heavy mountain snowfalls. This local research effort was undertaken to identify synoptic-scale and mesoscale patterns associated with heavy mountain snowfalls to determine if advances in NWP could predict these events, and provide forecasters at NWS BTV techniques and tools to assist in the prediction of these events.

As a direct result from the CSTAR project, St. Jean and Sisson (2004) found the following factors to be critical ingredients for forecasting upslope snow in Vermont and northern New York.

- Cutoff low (500 hPa) to the east/northeast of the region.
  - resulting in strong northwest flow aloft (greater than or equal to 50-kt).
- A nearly saturated environment
  - greater than 75% relative humidity from the surface to ridge top level. *(A deeper layer may actually be needed, i.e. surface to 10K ft.)*
- Strong low level winds
  - Greater than or equal to 20-kt at 925 hPa and greater than or equal to 30-kt at 850 hPa.
  - Significant cross-barrier component (wind direction 270-320 degrees).
- Convective Instability
  - Equivalent potential temperature decreasing with height in the low levels.
  - Steep low level lapse rates (at least 5.5°C/km).
- Favorable dendritic snow growth region
  - Strong upward Omega at -12 to -18°C.
- Cold air advection in the low levels.
- Event duration of at least 12 hours *(may be one of the most critical parameters)*.

These factors are incorporated into a forecaster checklist and conceptual model used at the NWS Burlington forecast office.

4. CASE OF 13-14 NOVEMBER 2003

The results of St.Jean and Sisson (2004) were applied to a heavy mountain snowfall on 13-14 November 2003 in Vermont and northern New York. This event produced over 12 inches of snowfall in the mountains and only a trace of snow in the Champlain Valley (Fig.2). Radar composite reflectivity from the NWS BTV WSR-88D is shown in Fig. 3. Reflectivity of greater than 20 dBZ occurred over and on the windward slopes of the northern Green and Adirondack mountains. The snow fell for a 12-18 h period from 2100 UTC 13 November 2003 until 1500 UTC 14 November 2003. To transfer the results of the CSTAR project to NWS operations, AWIPS procedures were specifically developed to examine elements of the forecast checklist for heavy mountain snow events with the national 12-km ETA (Fig. 4), and the local 5-km workstation ETA model (Figs. 5, 6). Using these procedures to assess the threat of a heavy mountain snowfall, NWS BTV was able to successfully forecast the event several days in advance. Fig. 4 shows an AWIPS 4-panel display of the locally developed procedure for upslope snow forecasting which incorporate the critical ingredients for forecasting upslope snow events. These include a 500 hPa low center located over northern ME, 850 hPa wind greater than 50 kt, relative humidity greater than 80%, 1000-850 hPa lapse rates greater than 6.5 ºC km^{-1}, and the location of the ETA model accumulated precipitation forecast located over the mountainous terrain, which were all present in the November 2003 event. Fig. 5 shows favorable dendritic snow growth (Waldstreicher 2002) was indicated at Underhill, VT on the windward side of Mt. Mansfield (4393 ft MSL), the highest point in VT, by the 5-km workstation ETA. The workstation ETA also produced a realistic pattern of 24-h accumulated precipitation forecast for this region with over one inch of liquid equivalent precipitation forecast over the northern Green mountains in the 24-h ending at 1500 UTC 14 November 2003 (Fig. 6).

NWS BTV, using the forecast checklist and high resolution NWP model forecasts, was able to issue a Winter Storm outlook more than 2 days (55 hr) in advance to alert the public of the potential for heavy snow in the mountains. A Winter Storm Watch preceded the event by 43 hours. Winter storm warning verification statistics of the event yielded a POD of 1.00, a FAR of 0.10, and LT of nearly 19 hours (Table 1). These statistics show a dramatic improvement in the warning service with an increase of 149% in POD, 200% decrease in FAR, and increase 190% in LT when compared with the 15-16 November 1999 case.

5. SUMMARY

NWS offices performing research in collaboration with Universities can lead to improved predictions of local weather phenomena. Synoptic-scale and mesoscale patterns associated with these phenomena are identified. Advances in local NWP are shown to assist the forecaster in the prediction of these events. Local forecast techniques and tools developed for upslope snow events and used by the NWS BTV forecasters are illustrated. The transfer of the research results to NWS operational forecasters through specifically developed AWIPS forecast display procedures is also discussed. Warning event statistics for these three upslope snow events are shown, since they are useful as some measure of the successful transfer of the research and technology to operational weather forecasting. More cases of heavy mountain snowfall in the Green and Adirondack mountains are needed to determine how successful the checklist and forecast procedures are in predicting these kinds of events.

ACKNOWLEDGEMENTS

Heather Hauser at the NWS Eastern Region Headquarters, Scientific Services Division, provided invaluable feedback during the submission of this manuscript. This work was completed in conjunction with the University at Albany/SUNY as part of the CSTAR program, supported by NOAA grant 1007941-1-012365. Additional information regarding the University at Albany CSTAR program may be found at http://cstar.cestm.albany.edu.

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Waldstreicher, J.S., 2002: A foot of snow from a 3000-foot cloud: The ocean-effect snowstorm of 14 January 1999. *Bull. Amer. Meteor. Soc.*, **83**, 19-22.

FIGURES

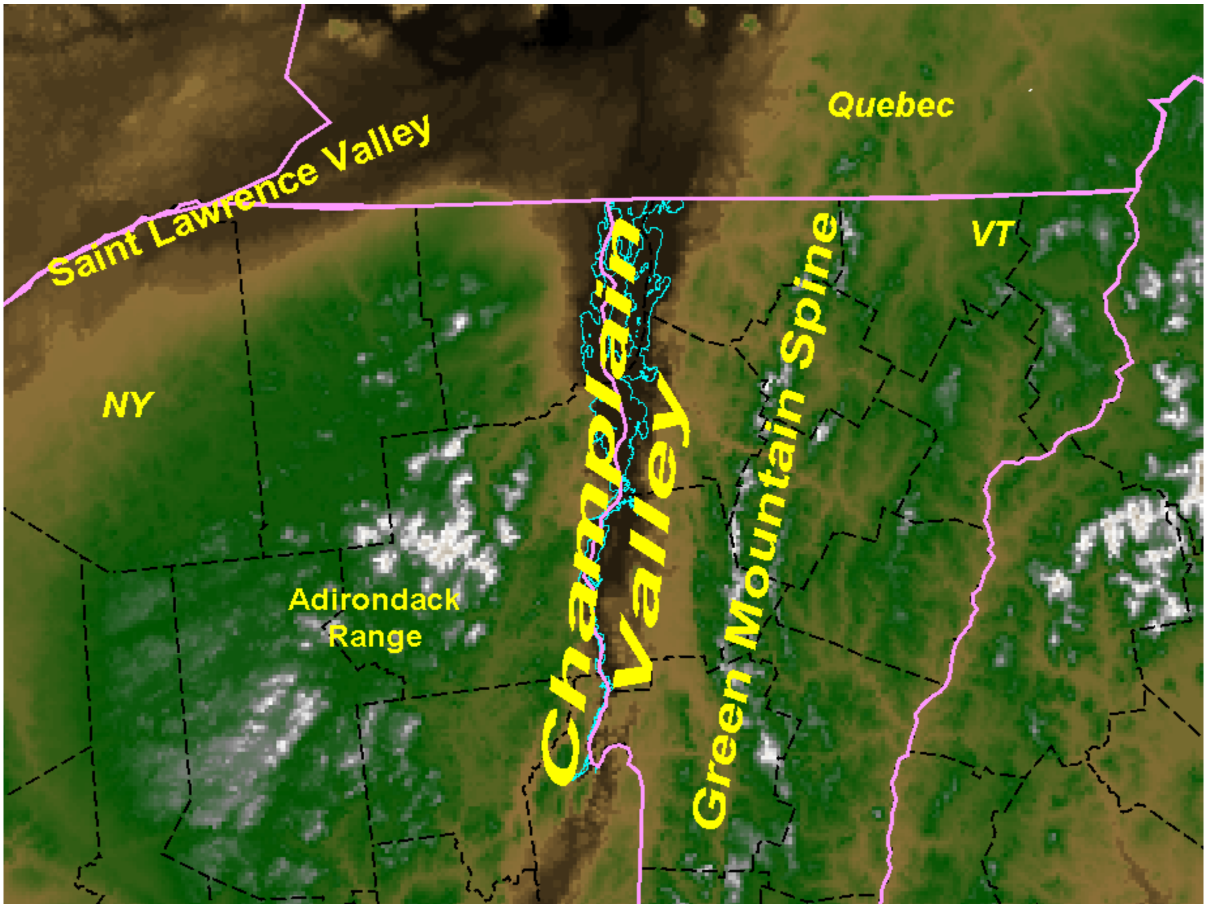

Fig. 1. Topography and main topographic features of the NWS BTV county warning area in northern NY and VT.

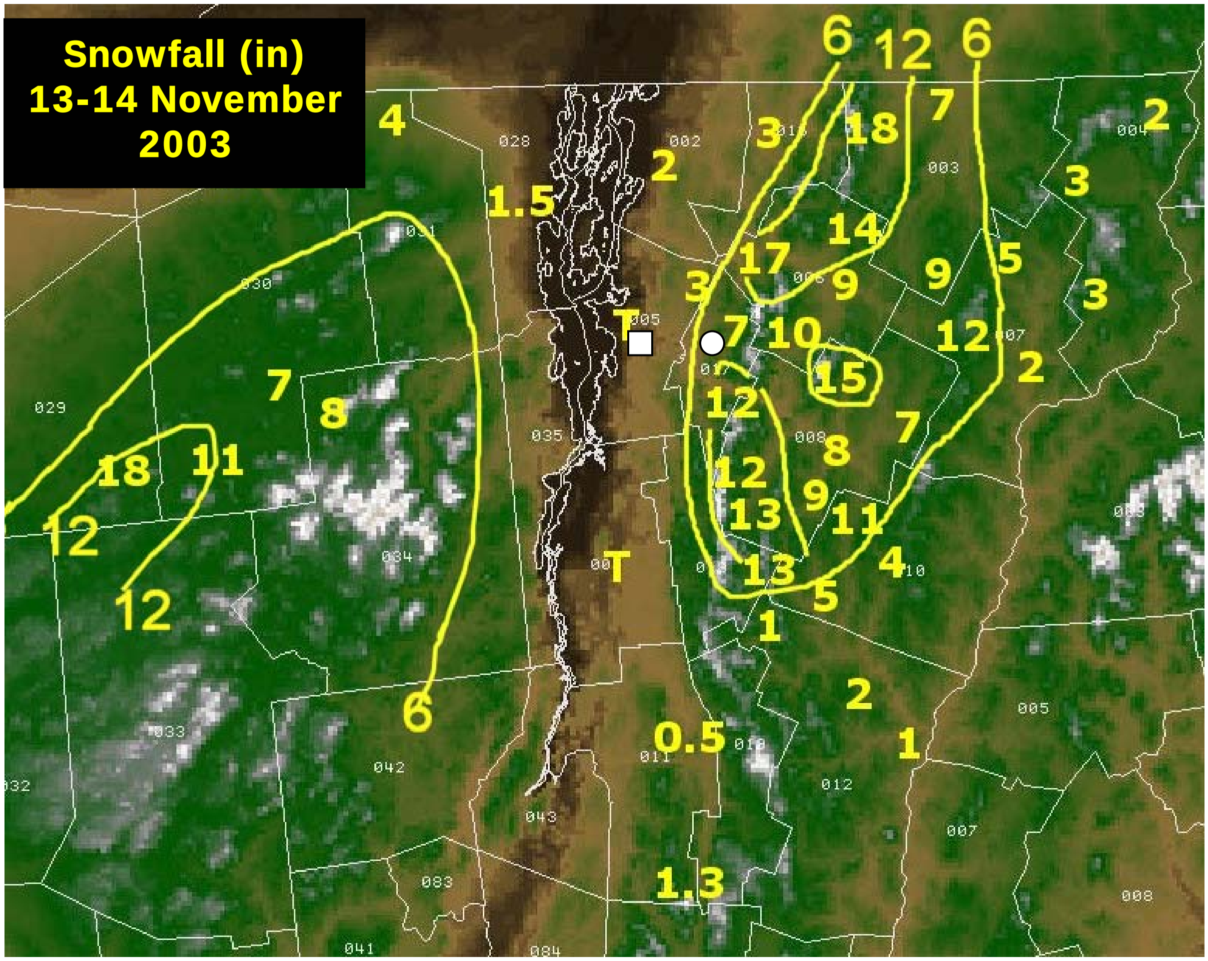

Fig. 2. Snowfall (solid, in) for 13-14 November 2003. Solid square indicates the location of Burlington, VT (KBTV) and the solid circle is the location of Underhill, VT on the windward slope of the highest point in VT on the Green Mountain ridge.

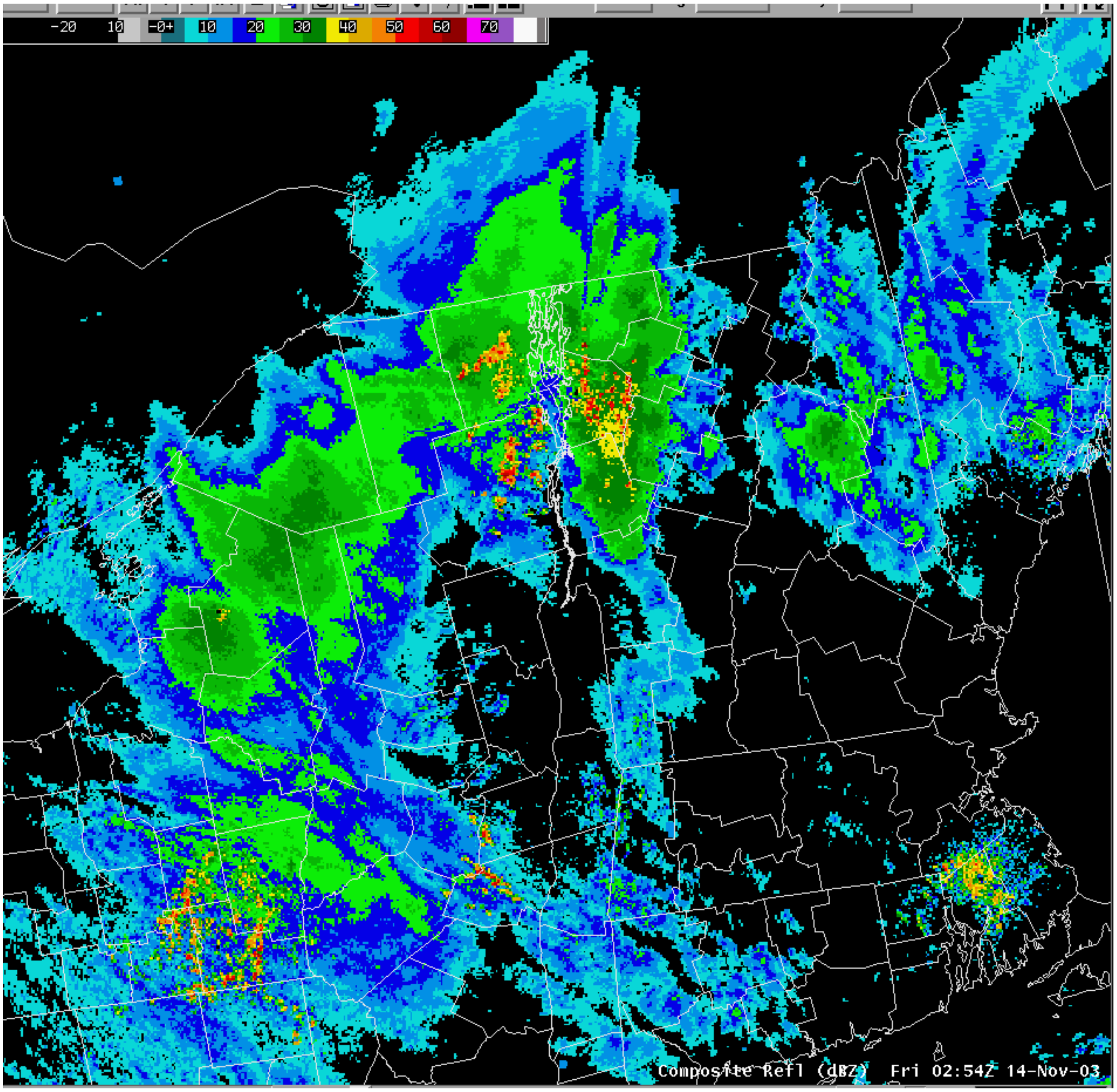

Fig. 3. NWS WSR-88D composite Reflectivity (dBZ) at 0254 UTC 14 November 2003.

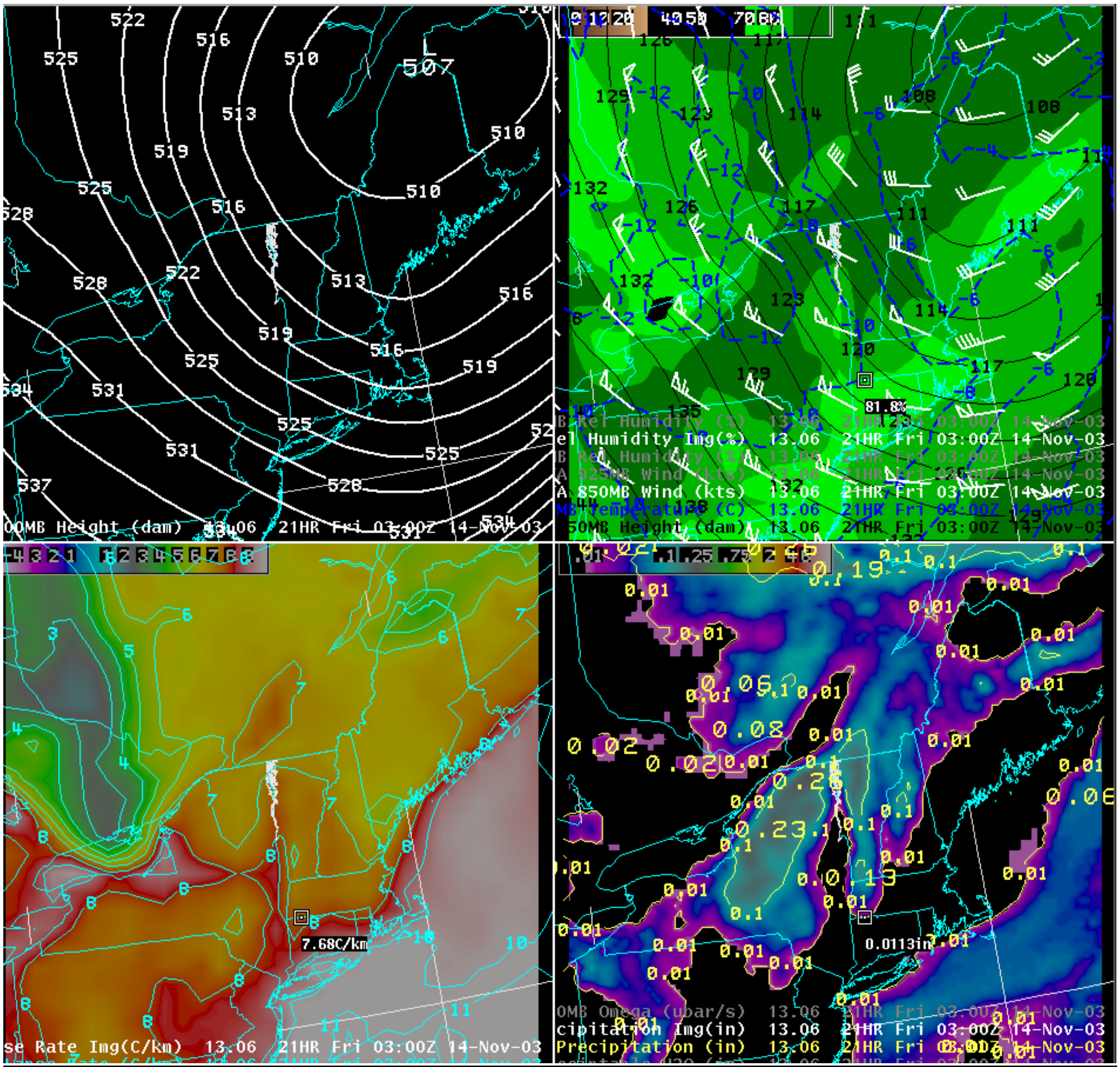

Fig. 4. AWIPS ETA model 21-h forecast from 0600 UTC 13 November 2003 valid at 0300 UTC 14 November 2003. This AWIPS 4-panel shows the locally developed upslope forecast procedure that employs the ingredients based upslope snow conceptual model. The upper left panel depicts 500 hPa heights (dm). The upper right panel depicts 850 hPa heights (solid, dm), 850 hPa relative humidity (shaded at 10% intervals greater than 70%), 850 hPa wind barbs (kt), and 850 hPa temperature (dashed, ºC). The lower left panel is the 1000-850 hPa lapse rate (ºC km^{-1}). The lower right panel is the 3-h accumulated quantitative precipitation forecast (in.).

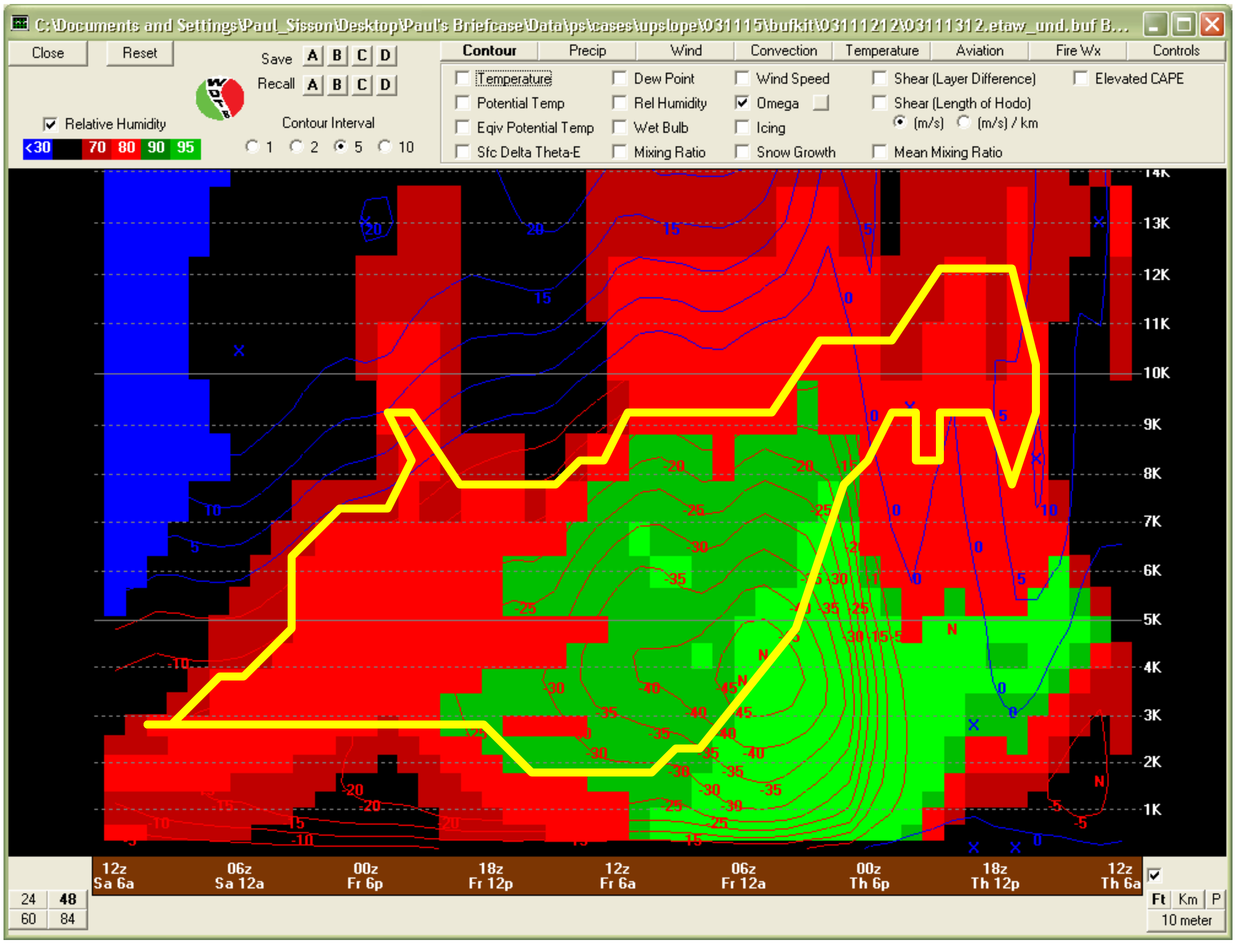

Fig. 5. Time cross section (time increasing from right to left) from the 1200 UTC 13 November 2003 5-km workstation ETA model for Underhill, VT. Relative humidity (shaded,%) dark red greater than 70%, light red greater than 80%, dark green greater than 90 % and light green greater than or 95 %. Omega (thin solid, µbar s^{-1}) contour interval of 5 µbar s^{-1}. Area enclosed by thick solid yellow contours indicates where relative humidity is greater than 80% and temperature is between -12 and -18 ºC.

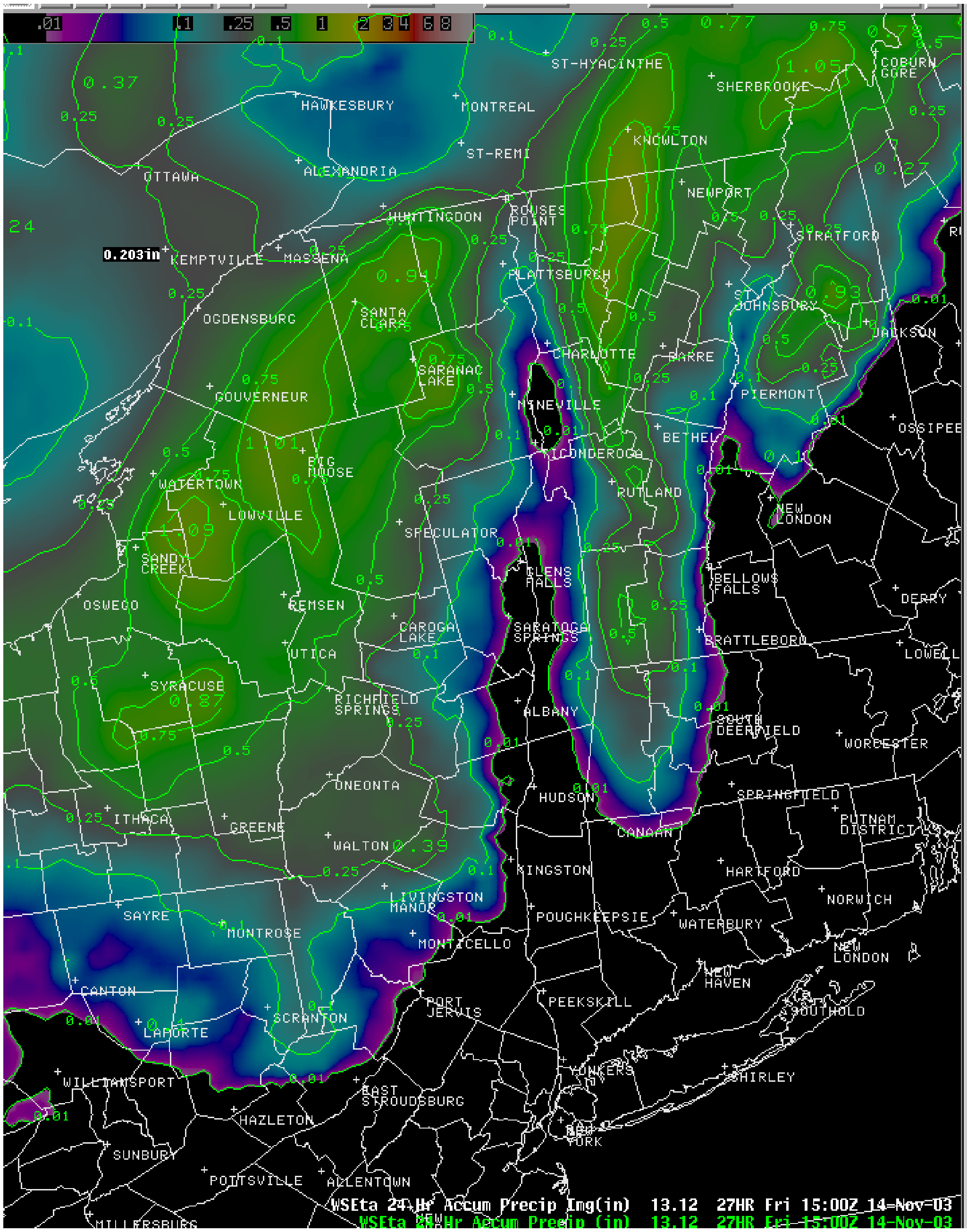

Fig. 6. 24 h accumulated precipitation forecast from the 1200 UTC 13 November 2003 5-km workstation ETA model valid at 1500 UTC 14 November 2003.

Table 1. Winter Storm Warning verification statistics by forecast zone for the NWS Burlington, VT forecast office.

Date	Probability of Detection (POD)	False Alarm Rate (FAR)	Lead Time (h)
15-16 Nov 1999	0.67	0.20	10 hrs
2-3 Mar 2000	0.00	1.00	0 hrs
13-14 Nov 2003	**1.00**	**0.10**	**19 hrs**