18.4 CHARACTERISTICS OF UPSLOPE SNOWFALL EVENTS IN NORTHERN NEW YORK STATE AND NORTHERN VERMONT: DIAGNOSTICS AND MODEL SIMULATIONS OF SEVERAL NORTHWEST-FLOW CASES

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1. INTRODUCTION

Over the northeastern United States, northwesterly lower-tropospheric flow regimes are occasionally associated with production of heavy precipitation, especially over the considerable orography of northern New York and northern New England. When associated with cutoff cyclones, these northwesterly flow events present difficult forecast challenges, due to numerical models' inherent problems in accurately forecasting the location and strength of cutoff cyclones (Smith et al. 2002).

The interaction of such a flow regime with the complex terrain of the northeastern United States often introduces substantial sub-synoptic-scale and mesoscale precipitation. This enhanced precipitation, generally on the upstream side of the cyclone, occurs where the low-level flow pattern is generally perpendicular to the local terrain.

Two cutoff 500 hPa cyclone events in the autumn of 1999 produced heavy snowfall over the mountains of northern New York State and northern Vermont. These two cases provided an operational impetus for studying the characteristics of these upslope snowfall events. The goal of this research is to produce ingredients-based conceptual models and operational methodologies for the purpose of improved prediction of the precipitation patterns produced by these flow regimes in the complex terrain of the northeastern United States.

2. METHODOLOGY

Cases selected for this study were limited to events occurring with prevailing deep-tropospheric northwesterly flow, which excluded any cases involving rapidly deepening coastal cyclones (i.e., Nor'easters). Northwest-flow scenarios generally produce a significant low-level flow component orthogonal to the Green Mountains and Adirondack Range, which is favorable for the generation or enhancement of heavy precipitation by orographic lift. Six scenarios have been examined in this study: three events which produced heavy snowfall in northern Vermont and northern New York State (including the two aforementioned events from 1999); two events which had been forecast to produce heavy snowfall, yet significant precipitation failed to occur; and one weak northwest-flow event. The details of one of the heavy snowfall events and one of the null events will be further discussed below.

Analyses from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis dataset (Kalnay et al. 1996; Kistler et al. 2001) were used in determining the synoptic-scale characteristics of each of the cases, supplemented with ETA model BUFR sounding analysis data in order to interrogate the mesoscale structure of each event. NWS Burlington, VT (BTV) local storm data was employed to compare analyses and forecasts to storm snowfall and precipitation totals. Fig. 1 shows the location of relevant observation locations in the NWS BTV forecast area.

For two of the events (one heavy precipitation and one null case), 5-km grid spacing mesoscale ETA model simulations were performed both to isolate mesoscale signatures, and to compare with their coarser-resolution operational ETA model (40-km) counterparts.

3. RESULTS

Comparisons of the heavy snowfall case (16 November 1999) and the null case (3 March 2000) yielded some significant differences in the two regimes. The heavy snowfall case was characterized by a persistent, strong northwesterly flow at the 500 hPa and 850 hPa levels. Although both cases exhibited northwesterly low-level flow (i.e., cross-barrier to the Green Mountains and Adirondack Range), the low-level flow in the null case was considerably weaker across the NWS BTV forecast area and of shorter duration. Figs. 2 and 3 depict a snapshot comparison at these two pressure levels. Both cases were characterized by near-saturated conditions at low- and mid-levels. Fig. 4 illustrates this for the heavy snowfall case. Low static stability, implied by vertical profiles of equivalent potential temperature difference from the surface (Fig. 5), was present during the entire heavy snowfall event lifetime, whereas static stability increased over time in the null case (not shown).

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Low- and high-resolution model comparisons have yielded some measure of forecast success by the 5-km ETA. The 40-km ETA failed to produce any orographic precipitation signature for the heavy snowfall case (Fig. 6a). Furthermore, the strength of the ascent forecast by the 40-km ETA was very weak and centered in the Saint Lawrence River Valley of southern Quebec (Fig. 7a). The 5-km ETA showed a definitive upslope/downslope component to the low-level vertical motion field adjacent to the Green Mountains, and subsequently produced larger precipitation amounts which were clearly tied to the terrain. The null case ETA simulations (not shown) exhibited comparable differences between the 5-km and 40-km runs, but their low-level vertical motion and wind fields were much weaker than observed for the heavy snowfall case.

4. SUMMARY

Diagnostic findings from this study suggest several meteorological factors significant to the development of heavy precipitation from this type of flow regime: (a) the low-level moisture profile; (b) the strength and orientation of the low-level wind with respect to the orography; (c) the low-level static stability profile. Additionally, this combination of factors must exist for a long enough period of time in order to produce heavy precipitation and/or snowfall.

An ingredients-based conceptual model is currently being employed and evaluated at NWS BTV by operational forecasters during these potential upslope precipitation events. The conceptual model makes use of a checklist in which several specific factors are considered:

- Near-saturated conditions from the surface to ridgetop level
- Strong low-level winds (10 m s^{-1} at 925 hPa and 15 m s^{-1} at 850 hPa levels) with significant cross-barrier component (wind direction 270°–320°)
- Equivalent potential temperature decreasing with height in the low levels
- Steep low-level lapse rates
- Event duration of at least 12 hours

Ice microphysics processes favorable to the production of heavy snowfall, such as dendritic snowflake growth (Waldstreicher 2002), also appear to be occurring in the upslope regions during the heavy snowfall events. Figure 4 shows near-saturated conditions in the favorable dendritic snowflake growth region (-12 to -18 °C) at Burlington, VT (i.e., in the upslope region) during the November 1999 heavy snowfall event. Ice microphysical processes, including dendritic snowflake growth and feeder-seeder mechanisms, are also considered by the operational forecaster when evaluating the potential for a heavy upslope snowfall event.

Procedures for viewing these parameters using the AWIPS (Advanced Weather Interactive Processing System) workstations are also being developed and tested at NWS BTV. After appropriate analysis, it is anticipated that these procedures will then be exported to other NWS offices in the northeastern United States for assessment of upslope snowfall potential.

5. ACKNOWLEDGMENTS

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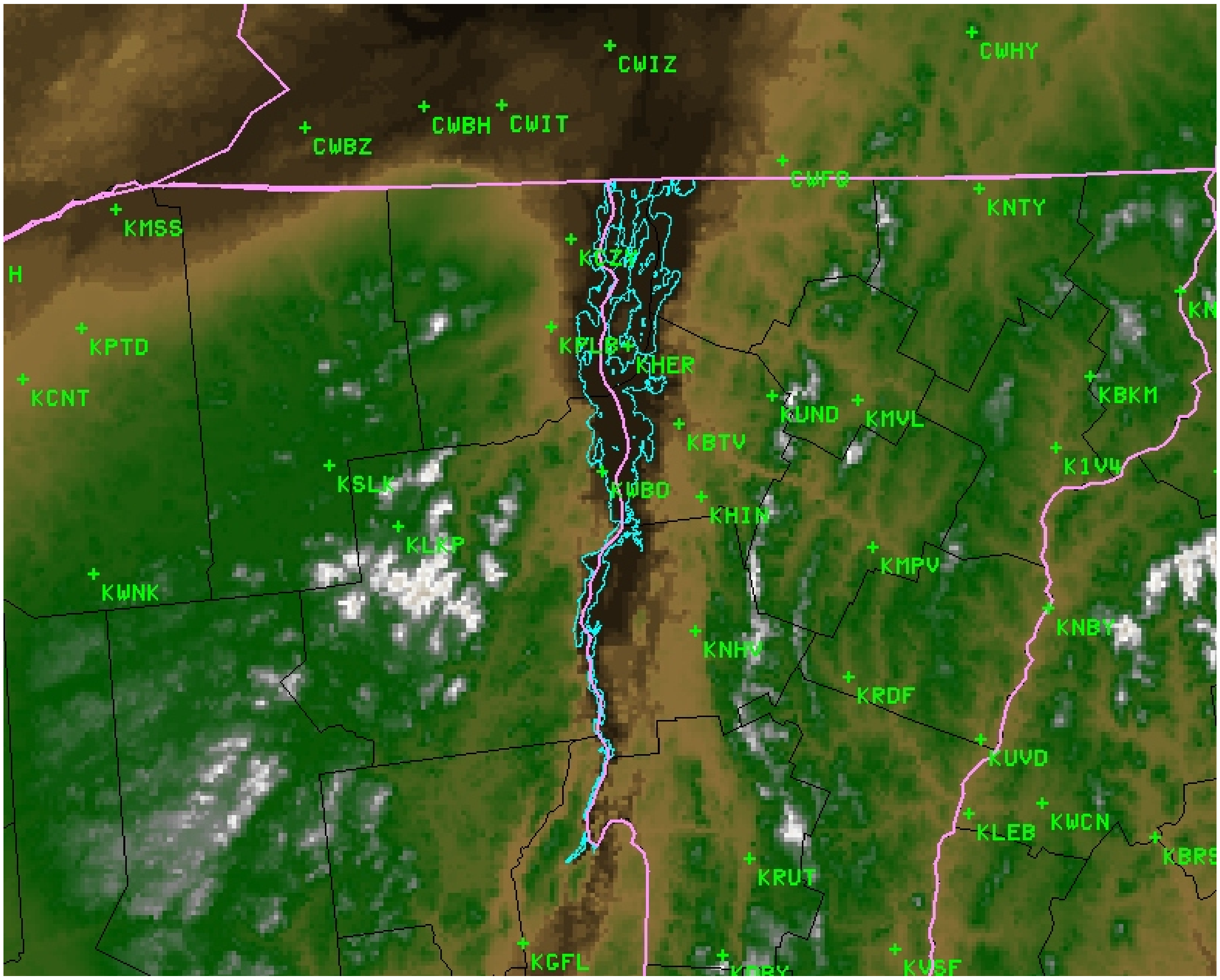
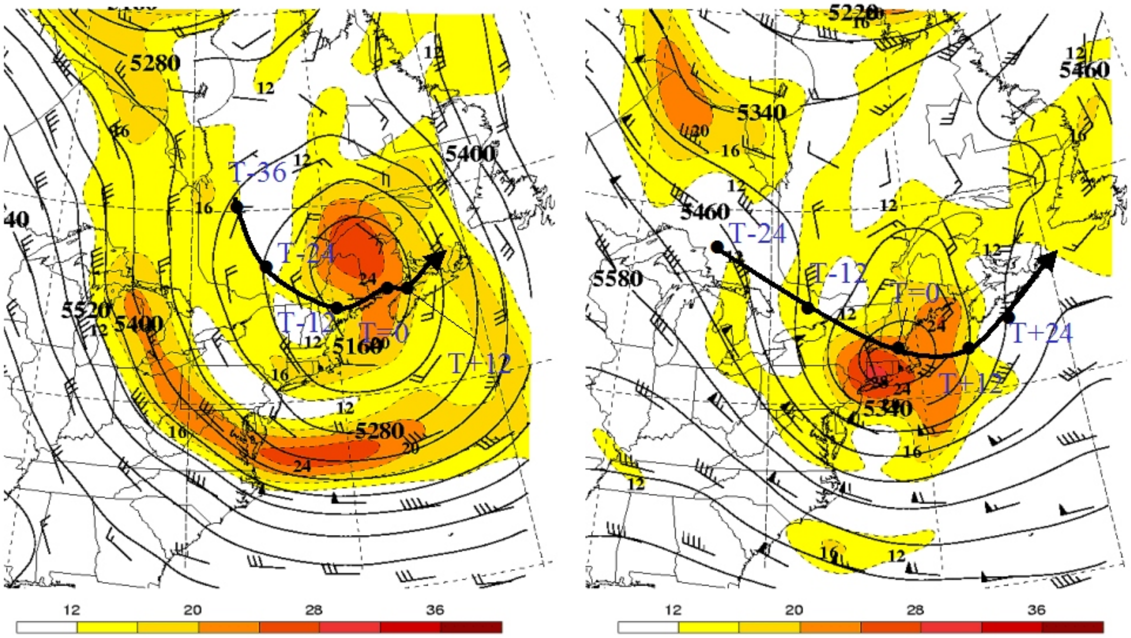


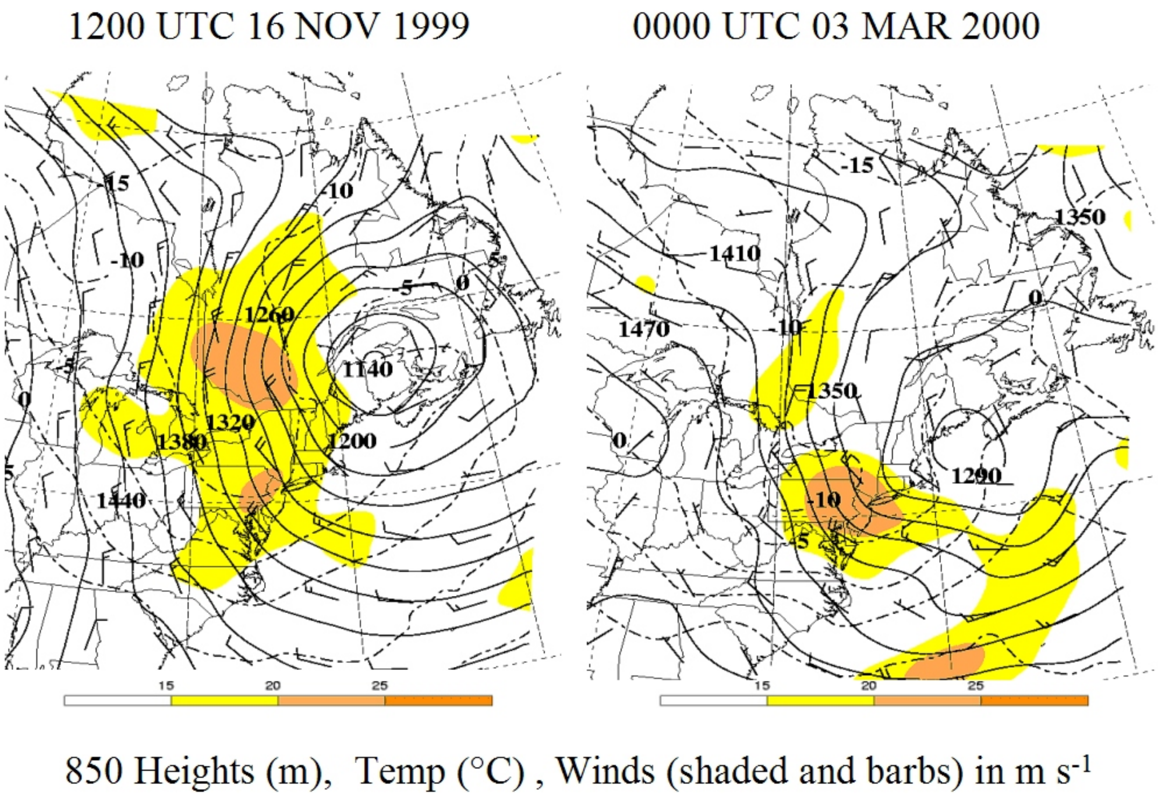
Fig. 1. Locations of METAR observation sites, NWS Cooperative observation sites, and local mesonet sites in the NWS Burlington, VT forecast area.



1200 UTC 16 NOV 1999 0000 UTC 03 MAR 2000

500 Heights (m), Abs. Vorticity (10^{-5} s^{-1}), Wind (m s^{-1})

Fig. 2. 500 hPa geopotential height (solid contours, m), absolute vorticity (shaded, 10^{-5} s^{-1}), and wind barbs (m s^{-1}) for (a) 1200 UTC 16 November 1999 and (b) 0000 UTC 3 March 2000. (12-hourly cyclone positions from time T-36 hours to T+24 hours are depicted as solid black dots and the analysis of the track is depicted by a thick black line.)



1200 UTC 16 NOV 1999

0000 UTC 03 MAR 2000

850 Heights (m), Temp (°C) , Winds (shaded and barbs) in m s^{-1}

Fig. 3. 850 hPa geopotential height (solid contours, m), temperature (dashed, °C), and wind (barbs with isotachs shaded, m s^{-1}) for (a) 1200 UTC 16 November 1999 and (b) 0000 UTC 3 March 2000.

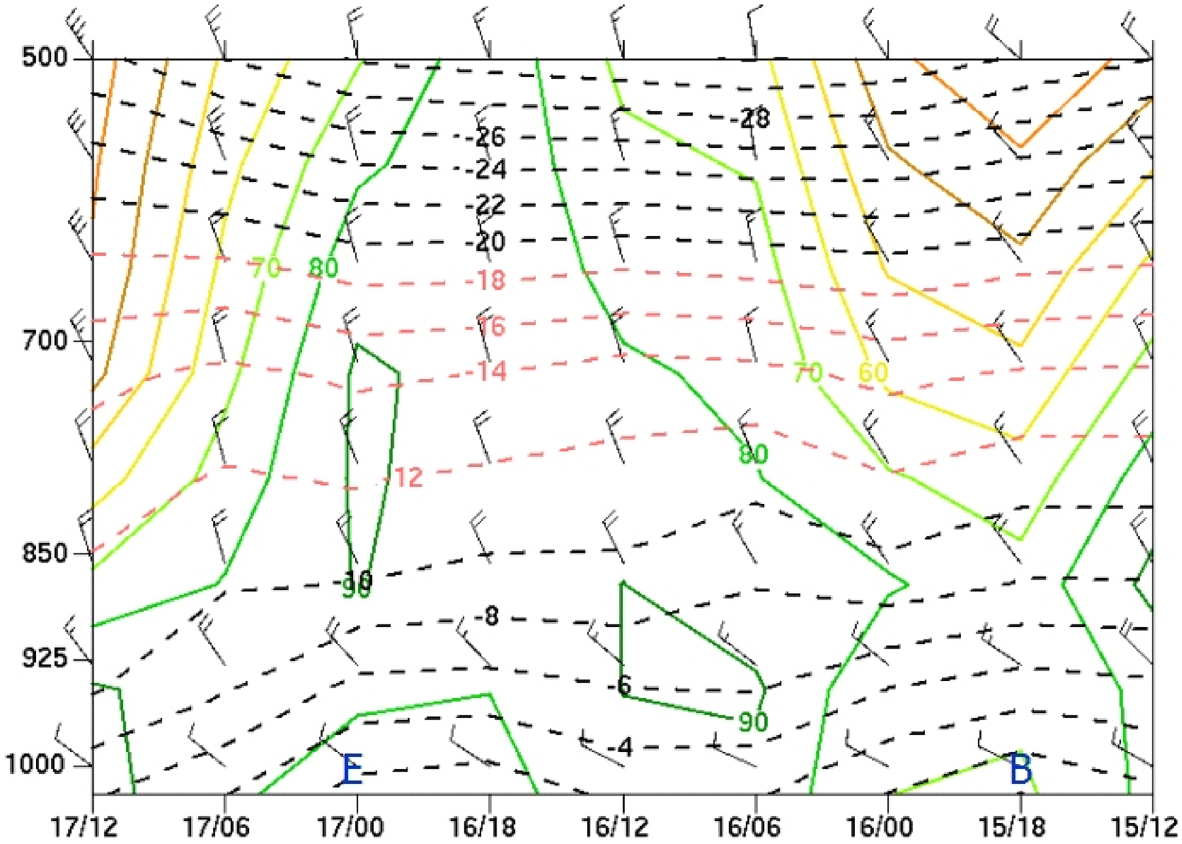


Fig. 4. Burlington, VT, time vs. pressure (hPa) analysis of wind (barbs, m s^{-1}), relative humidity (solid contours, percent), and temperature (dashed contours, °C), from 1200 UTC 15 November 1999 to 1200 UTC 17 November 1999. 'B' indicates the beginning of the upslope precipitation event; 'E' indicates the end of the event.

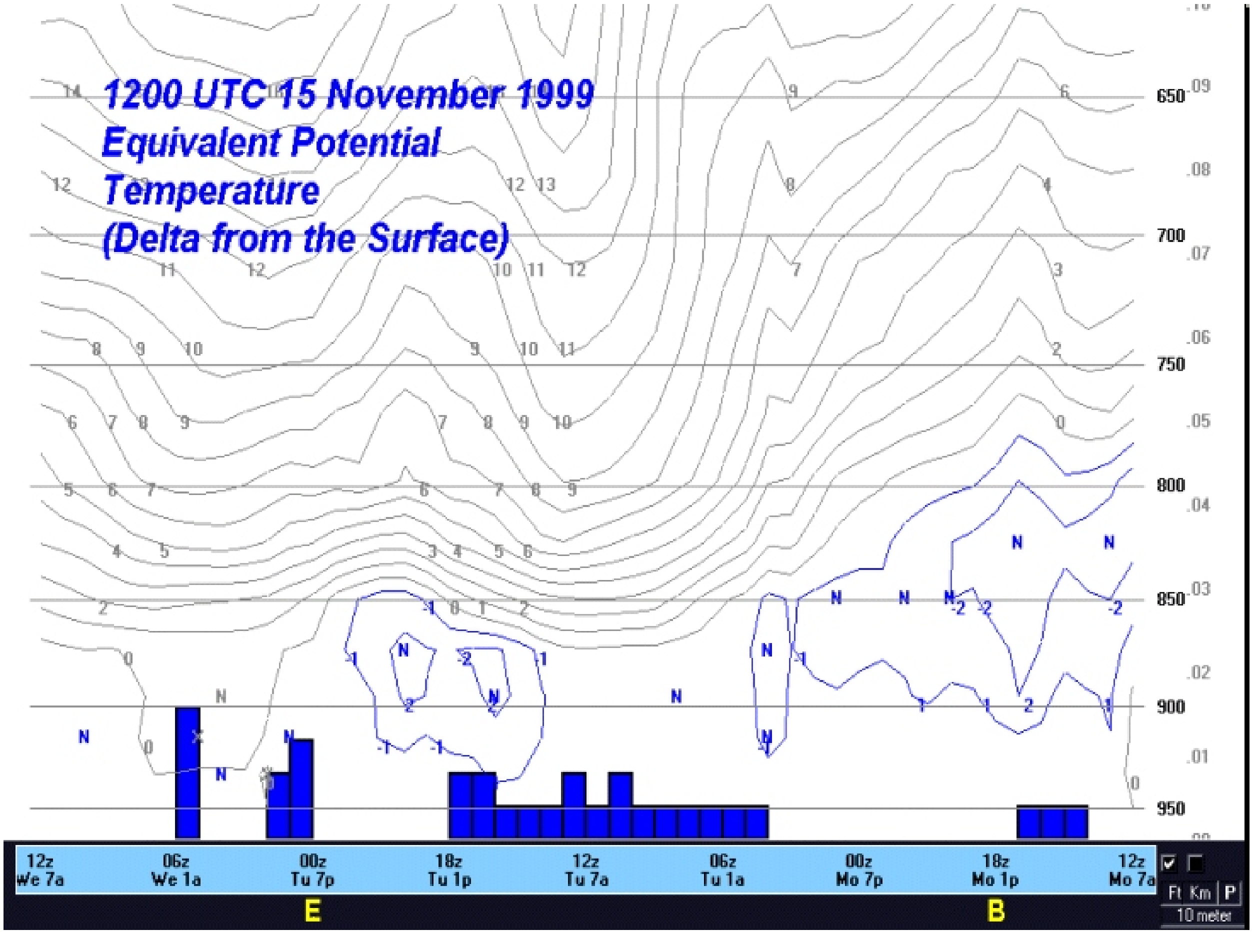


Fig. 5. Burlington, VT operational Eta model time vs. pressure (hPa) forecast of equivalent potential temperature difference from the surface (negative values are contoured in bold, °C), and hourly precipitation (blue vertical bars, 10^{-2} in.), from 1200 UTC 15 November 1999 to 1200 UTC 17 November 1999. 'B' indicates the beginning of the upslope precipitation event; 'E' indicates the end of the event.

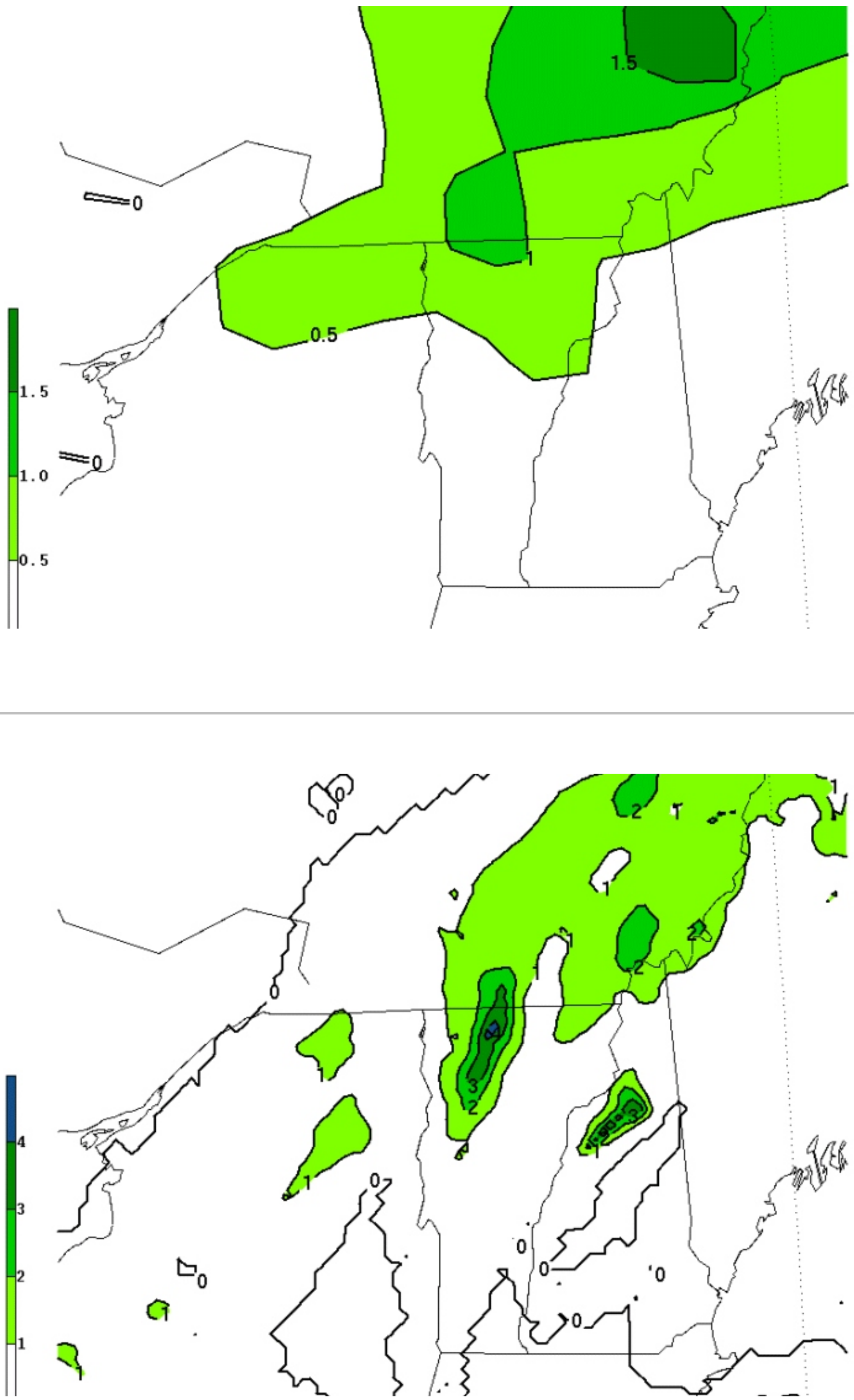


Fig. 6. 30-hour forecast precipitation (cm) valid 0000 UTC 17 November 1999, from: (a) 40-km horizontal grid spacing Eta model run (0.5 cm contour interval, shaded above 0.5 cm); (b) 5-km horizontal grid spacing Eta model run (1.0 cm contour interval, shaded above 1.0 cm).

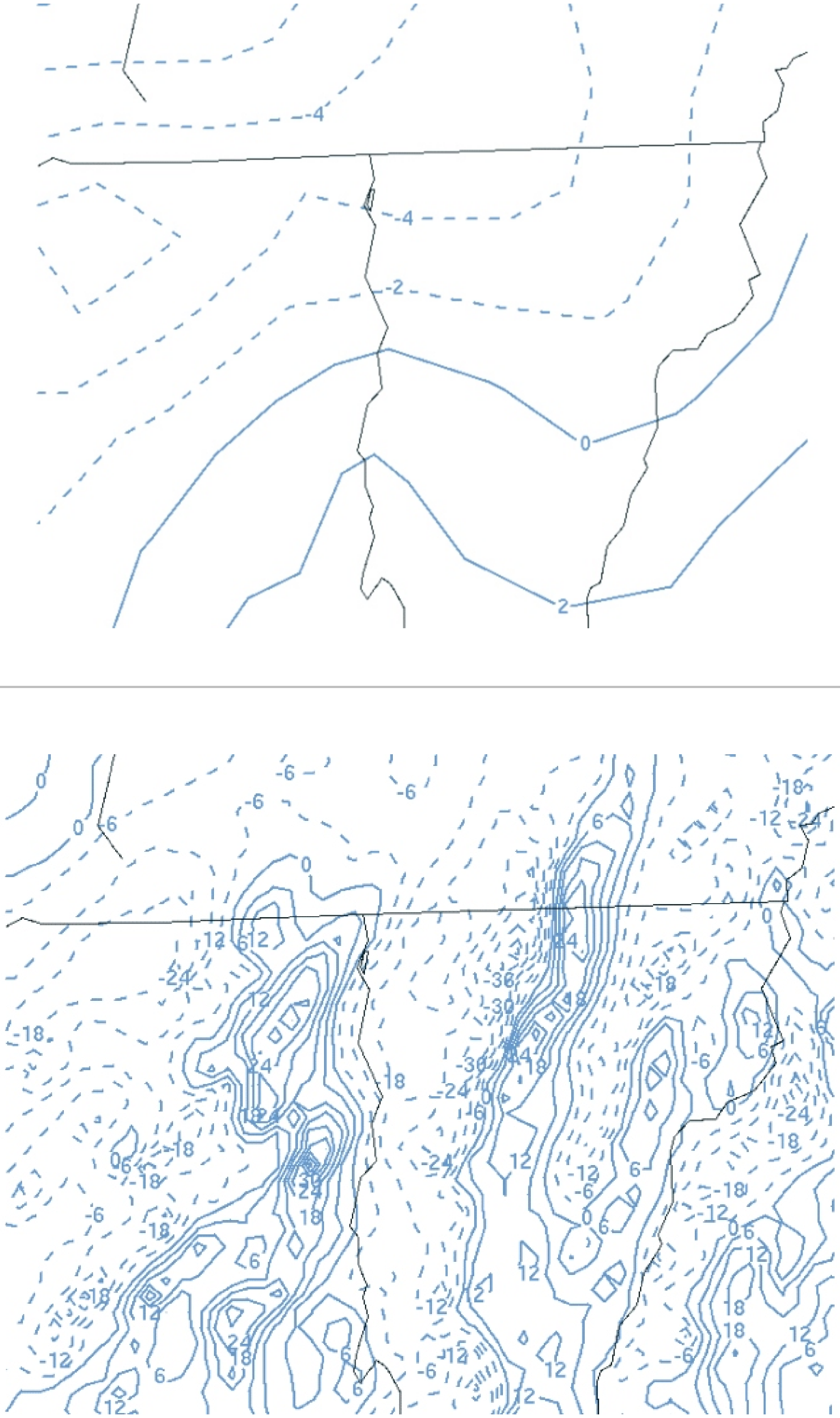


Fig. 7. 24-hour forecast of 925 hPa omega (10^{-3} s^{-1}), valid 1200 UTC 16 November 1999, over northern Vermont and northeastern New York, from: (a) 40-km horizontal grid spacing Eta model run; (b) 5-km horizontal grid spacing Eta model run.