# P9.1 A CONCEPTUAL MODEL OF WARM SEASON EXCESSIVE RAINFALL USED TO WARN FOR FLOODING OF 12 JUNE 2002 ACROSS NORTHERN VERMONT

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## 1. INTRODUCTION

Historically, flooding has been and continues to remain the greatest natural disaster to affect Vermont. The Great Flood of November 1927 claimed 84 lives, including the life of the Lieutenant Governor. Recently, there have been 8 Federally-declared flood disasters in Vermont (1992 to 2002), resulting in millions of dollars in damage as well as some fatalities.

Flood disasters in Vermont occur in both the cool season (winter and spring) and warm season (summer and fall). Cool season events often have saturated or impervious soils due to snow cover or frozen ground, and widespread duration rainfall produced by upper jet dynamics. Warm season events typically have the most intense rainfall produced by low level convergence or instability, and large amounts of atmospheric moisture.

The greatest (severe) flooding often results when long-duration heavy rainfall occurs across a widespread area of saturated ground and steep terrain. The mountainous terrain of Vermont's Green Mountains contains numerous small river basins with steep slopes. In these basins, terrain relief reaches as high as 4000 feet, which contributes to rapid runoff of heavy rainfall.

The 12 June 2002 flood event was a warm season flood event but also had some elements of a cool season flood. It was focused over some of Vermont's steepest terrain, already saturated by a previous rainfall event. Unseasonably strong jet dynamics combined with warm season moisture and stationary low level convergence produced a wide band of moderate to heavy rainfall and a concentrated band of flood-producing excessive rainfall.

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Figure 1 shows the 24-hour rainfall from this event with widespread rainfall amounts exceeding 0.50-in (13 mm) across the northern third of New York and northern two-thirds of Vermont. Note the narrower, linear "banded" structure of the greater than 2 in (51 mm) and the localized greater than 3 in (76 mm) rainfall in mountainous locations along the Canadian border. Operational Numerical Weather Prediction (NWP) model quantitative precipitation forecast (QPF) fields adequately predicted the synoptic scale rainfall amounts and location. However, these models may have lacked the mesoscale detail needed to forecast localized rainfall amounts that exceeded twice the QPF values.

A locally developed conceptual model of warm season excessive rainfall events in Vermont was used to effectively assess and warn for the flooding on 12 June 2002. Section 2 will discuss the conceptual model and Section 3 will show how this case is consistent with the model. Section 4 will review the forecast and warning decisions made on 11-12 June 2002 and Section 5 will describe the observed rainfall and flooding. This study demonstrates the value of developing conceptual models for use in the forecast process.

## 2. CONCEPTUAL MODEL OF A WARM-SEASON EXCESSIVE RAINFALL EVENT IN NORTHERN VERMONT

The continual flooding problem in Vermont, especially over the last decade, has led NWS Burlington forecasters to the development of a conceptual model. This model depicts atmospheric conditions most favorable to produce excessive rainfall when superimposed on the topography of northern Vermont and serves as a "heads up" for closer interrogation of a possible flood event.

Research and case studies suggest the use of conceptual models and ingredient-based precipitation forecasts (Doswell et al. 1996) are valuable in recognition of heavy rainfall events.

Conceptual model parameters often linked to the occurrence of heavy rainfall include measures of absolute moisture, instability, and vertical motion. These parameters are useful in predicting rainfall intensity, but experience repeatedly demonstrates that the stationary nature of these parameters is often the key to heavy rainfall that results in flooding (Doswell et al. 1996).

Figure 2 is a conceptual model of meteorological ingredients conducive to heavy rainfall in northern New York, northern Vermont, and adjacent areas of southern Quebec. This conceptual model has been in use for nearly 10 years at NWS Burlington to help identify heavy rainfall events. Parameters shown (Fig. 2) produce vertical motion through low level overrunning of tightening thermal gradients (frontogenesis) at 850 hPa, directional and speed convergence at 850 hPa, topographic lift of low and mid level westerly flow, and upper divergence and indirect circulation of jet streaks (250 hPa). The conceptual model also includes abnormally high amounts of absolute moisture (Lapenta et al. 1995) with precipitable water frequently exceeding 1.5-in (38mm) and dew points at 850 hPa exceeding 12$^{o}$C.

Finally, total rainfall is greater when parameters remain stationary over the same area. In the model this generally occurs when there is a stationary front at 850 hPa, balanced between the inflow at 850 hPa and the low level outflow of the rain-cooled air. In some cases, upper air divergence and new areas of vertical motion redevelop upstream of existing convective cells, resulting in a zero net displacement as individual cells move downstream.

**3. NWP FORECASTS AND OBSERVATIONS CONSISTENT WITH CONCEPTUAL MODEL**

The 12 June 2002 event showed a strong correlation to the conceptual model, with low level overrunning and convergence, upper divergence, and abnormally large amounts of absolute moisture.

Figure 3 shows 0000 UTC 12 June 2002 MesoETA model analysis of frontogenesis at 850 hPa, and the tightening of thermal gradients where the overrunning ascent is maximized. This axis of frontogenesis over northern Vermont was crucial in forecasting where the greatest upward vertical motion would be focused (Nicosia and Grumm 1999, as well as showing the quasi-stationary nature of the boundary. Directional and speed convergence helped enhance the vertical lift along this boundary.

Figure 4 shows 1200 UTC 12 June 2002 12-hr forecasted upper divergence at 250 hPa in the right rear quadrant of an un-seasonably strong 120-140 knot jet max (color shaded). This upper divergence, also centered over northern Vermont, promoted deeper upward vertical motion above the area of 850 hPa frontogenesis during the period of forecasted heaviest rainfall. Observed precipitable water values at 0000 UTC 12 June 2002 (Fig. 5) were approximately 200% of normal for June, with greater than 1.5-in (38mm) over northern Vermont and available upstream.

**4. FORECAST AND WARNING DECISIONS**

QPF from all NWP models was 1 to 2 inches with this event, and basically in the correct area. However, forecasters recognized the similarity to the conceptual model and gained confidence to forecast rainfall amounts more than twice as large as the model QPF, and issue flood warnings more than 6 hours before flooding began.

Initial forecasts and flood watches, on the afternoon on 11 June 2002, generally reflected the placement and amounts of the model QPF, concentrating on northwestern Vermont in the areas of greatest upslope, steepest terrain, and saturated soils caused by 1 to 2 inches of rain in the preceding 10 days.

During the evening of 11 June 2002, satellite, radar, and upper air observations continued to align with the conceptual model. The accuracy of the MesoETA and ETA model forecasts of frontogenesis at 850 hPa and divergence at 250 hPa was becoming more apparent as areas of heaviest rain reformed in southern Quebec and moved southeastward in a narrow band across all of northern Vermont. At 0000 UTC 12 June 2002, flood watches were expanded to include the northern half of Vermont, and public statements were issued which mentioned greater than 4 inches of rainfall would be possible in less than 18 hours.

At midnight (EDT) 12 June 2002, locally more than 2 inches of rainfall was already estimated across northwestern Vermont, using the Weather Surveillance Radar (WSR-88D) at Colchester, Vermont (KCXX; Fig. 6). Rainfall rates of about 0.25 in (6mm) per hour were being observed. Upstream, over southeastern Ontario and southwestern Quebec, satellite imagery showed an expanding area of colder cloud tops (Fig. 7) indicative of deeper vertical motion yet to arrive in Vermont. Aware that several more hours of heavy rain was likely across northern Vermont, and that monitored river gauges were beginning to show substantial rises, forecasters issued county-wide flood warnings for Caledonia, Franklin, Lamoille, and Orleans counties in northern Vermont and mentioned specific river basins would be directly affected, including the Passumpsic and Missisquoi basins.

## 5. OBSERVED RAINFALL AND FLOODING

Storm total rainfall between 1200 UTC 11 June 2002 and 1400 UTC 12 June 2002 was 2.0 to 4.5in. (50 to 113mm) across the northern half of Vermont and northeastern New York. Figure 8 shows a few observed rainfall totals plotted over the storm total radar estimates from WSR-88D, KCXX. NWS cooperative observers in Vermont reported 4.50 in. (113mm) at Jay Peak, 4.30 in. (107mm) at Sutton and East Haven, and 4.20 in. (105mm) in Albany.

Substantial flooding occurred across several small watersheds across Caledonia, Franklin, Lamoille and Orleans counties beginning around 1000 UTC and continuing through the afternoon of 12 June 2002. These four counties were eventually declared Federal Disaster areas (FEMA-1428-DR).

The flood damage was greatest in the headwater regions of the Passumpsic and Missisquoi River basins. Figure 9 shows a time sequence of river gauge readings from the United States Geological Survey (USGS) river gauge on the East Branch of the Passumpsic River. Note the increase in volumetric flow that occurred between late morning on 11 June and late morning on 12 June, around a 4000% increase in flow and an estimated 100-year recurrence event. This was the highest river stage ever recorded on the East Branch of the Passumpsic River and on the Mississquoi River at North Troy, VT. Also during this event, the river stage measured at the mouth of the Passumpsic River was the second highest ever reported.

## 6. SUMMARY

Forecasters used a conceptual model to recognize the presence of critical ingredients for excessive rainfall, permitting issuance of accurate countywide flood watches, warnings and river flood warnings 6 hours before flooding developed.. NWP analysis and forecast products described areas of vertical motion and were helpful to refine location, intensity and duration of the rainfall, and to predict rainfall amounts and expand flood watches. Finally, careful monitoring of remote sensing tools like satellite, radar, and river gauges enabled forecasters to issue and refine flood warnings.

## ACKNOWLEDGEMENTS

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**FIGURES**

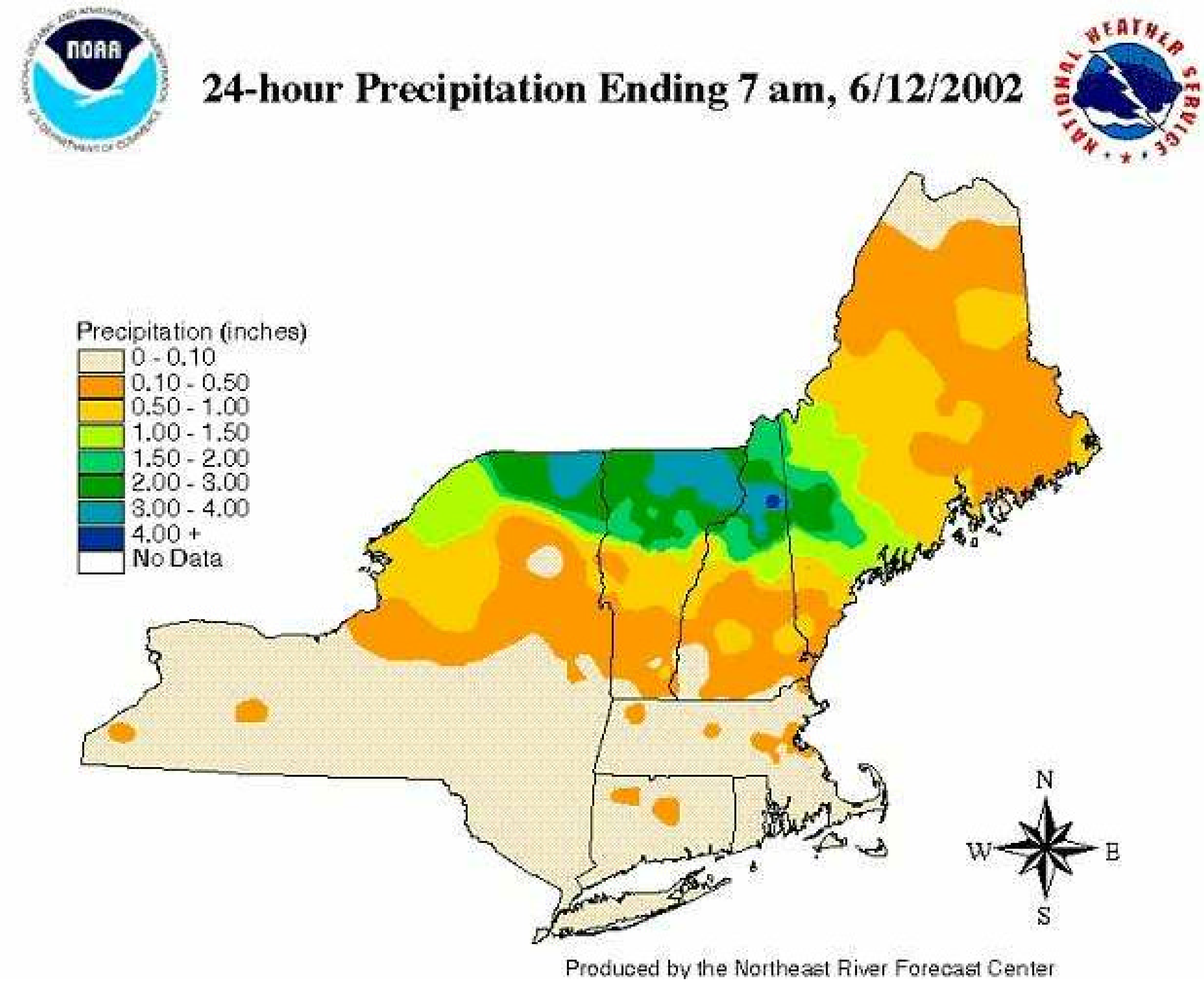


Fig. 1. 24 hour rainfall totals ending 7 am EDT 12 June 2002.

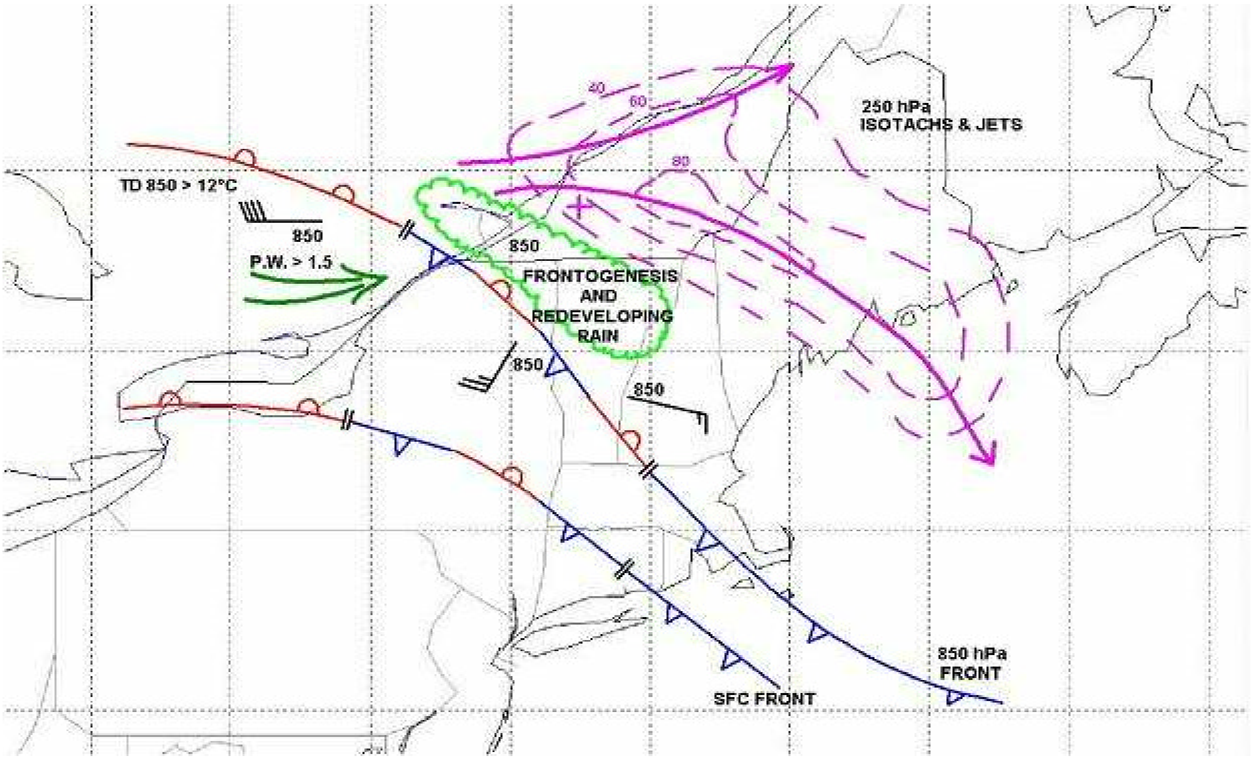

Fig. 2. New England warm season heavy precipitation conceptual model.

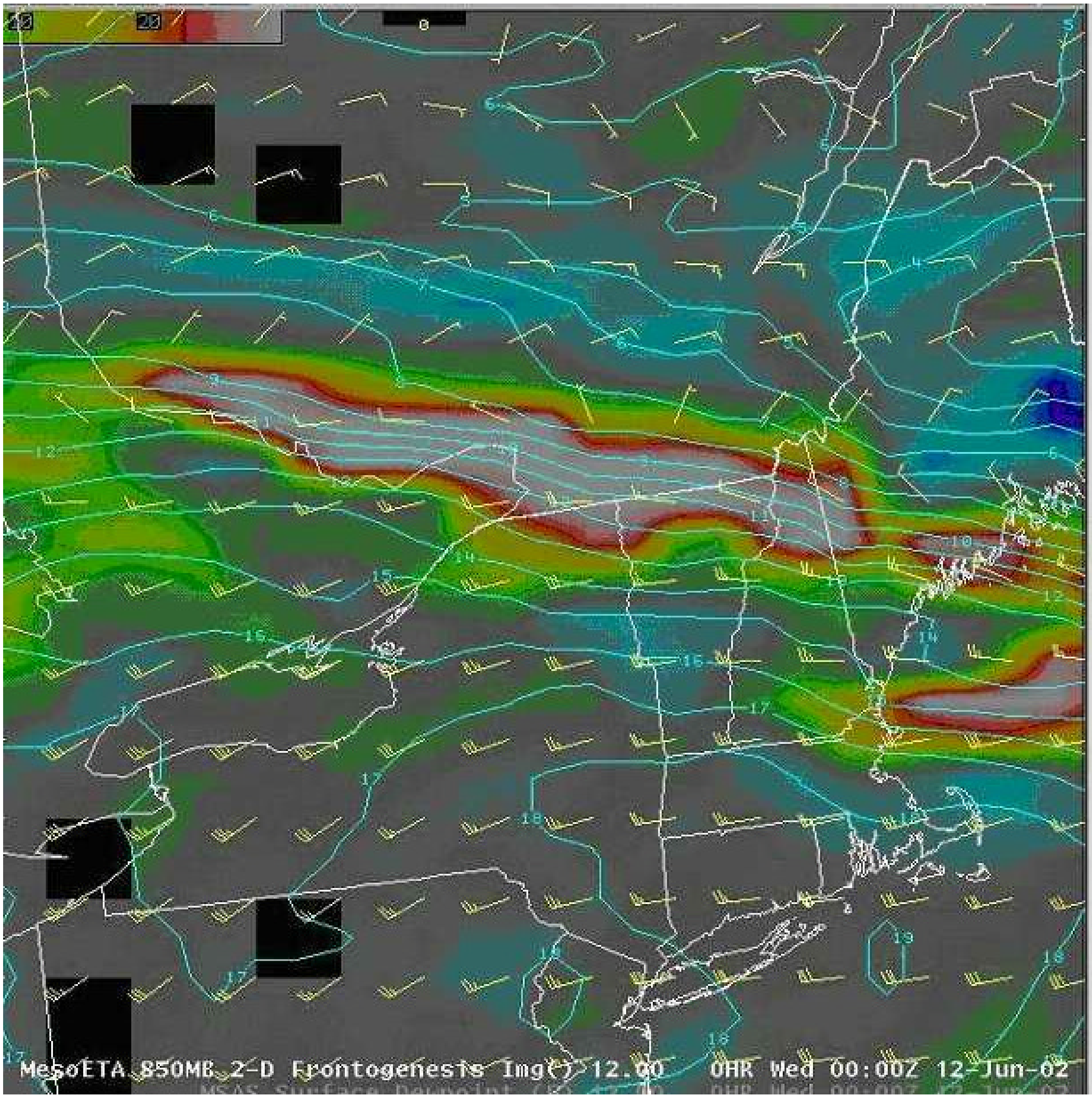


Fig. 3 MesoEta 0000 UTC 12 June 2002 analysis of 850 hPa Temperature (solid lines; **ºC**) and Frontogenesis (image; $K^{-2}/m^2/1x10^{-15}s$).

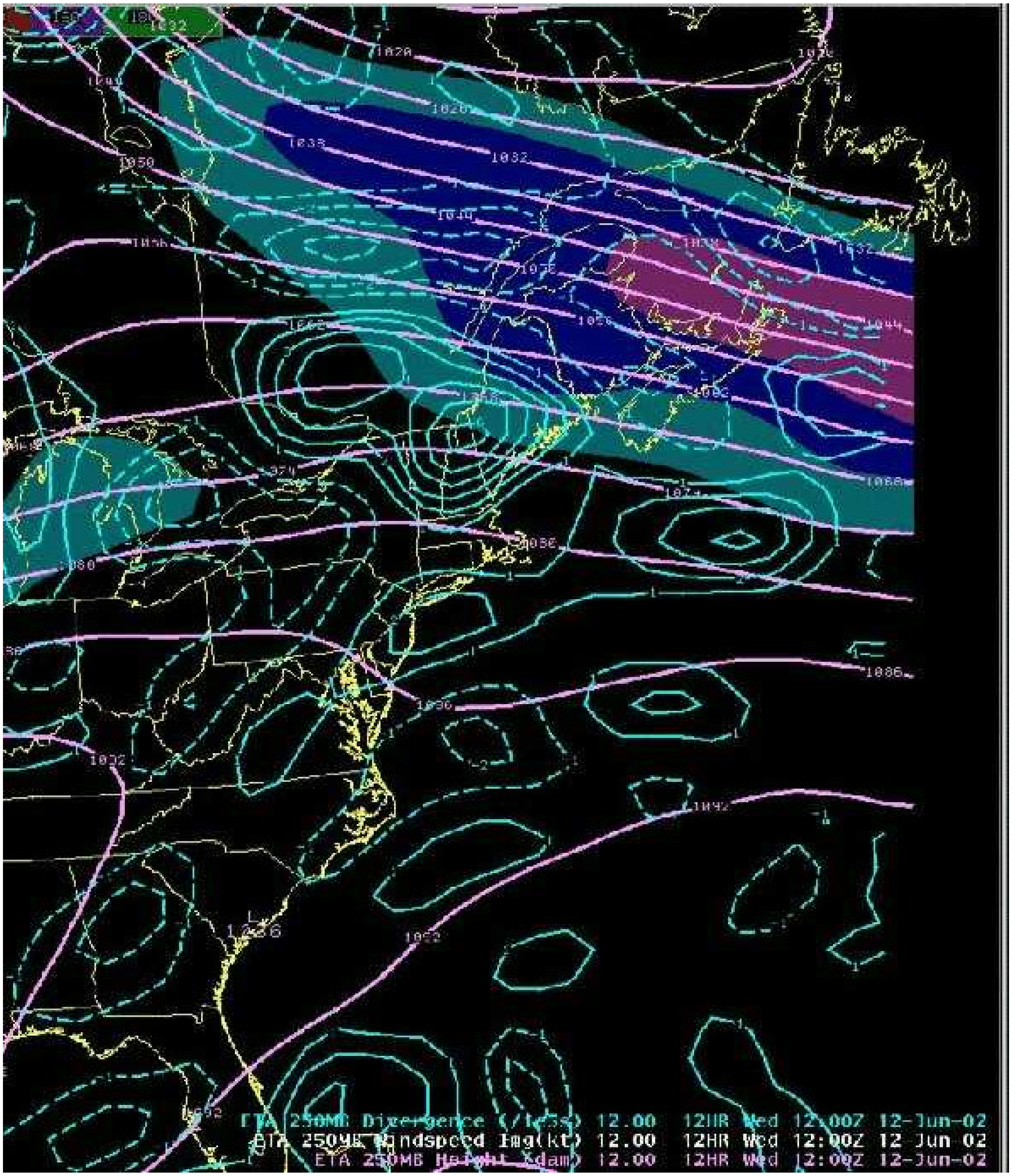


Fig. 4 ETA 12 hour forecast valid 1200 UTC 12 June 2002. 250 hPa windspeed (image; kt), 250 hPa heights (purple line; dam) and associated upper level divergence (solid blue line; $/1x10^{-5}s$).

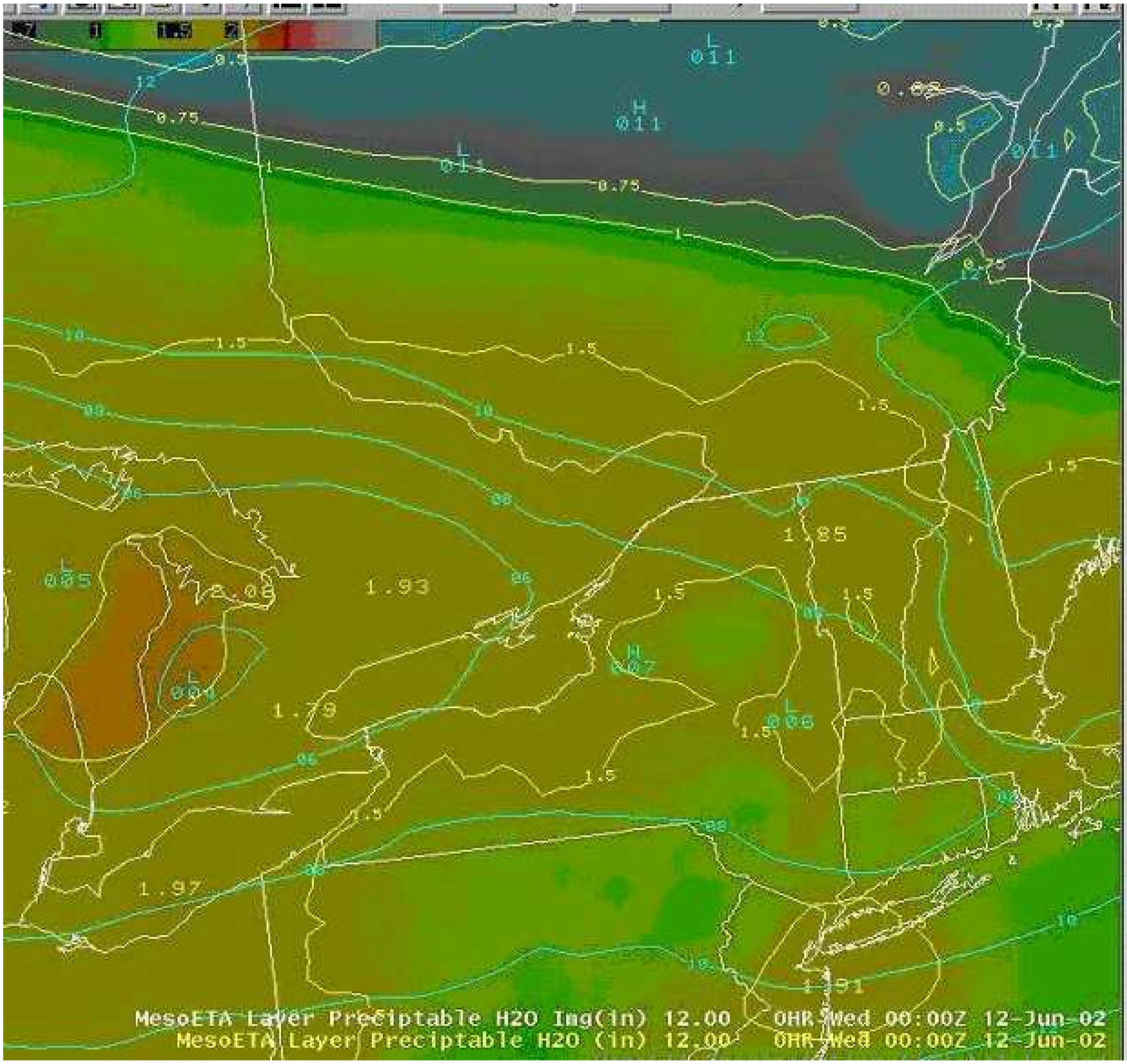


Fig. 5 MesoEta 0000 UTC 12 June 2002 analysis of Precipitable Water (Image and solid yellow line; in).

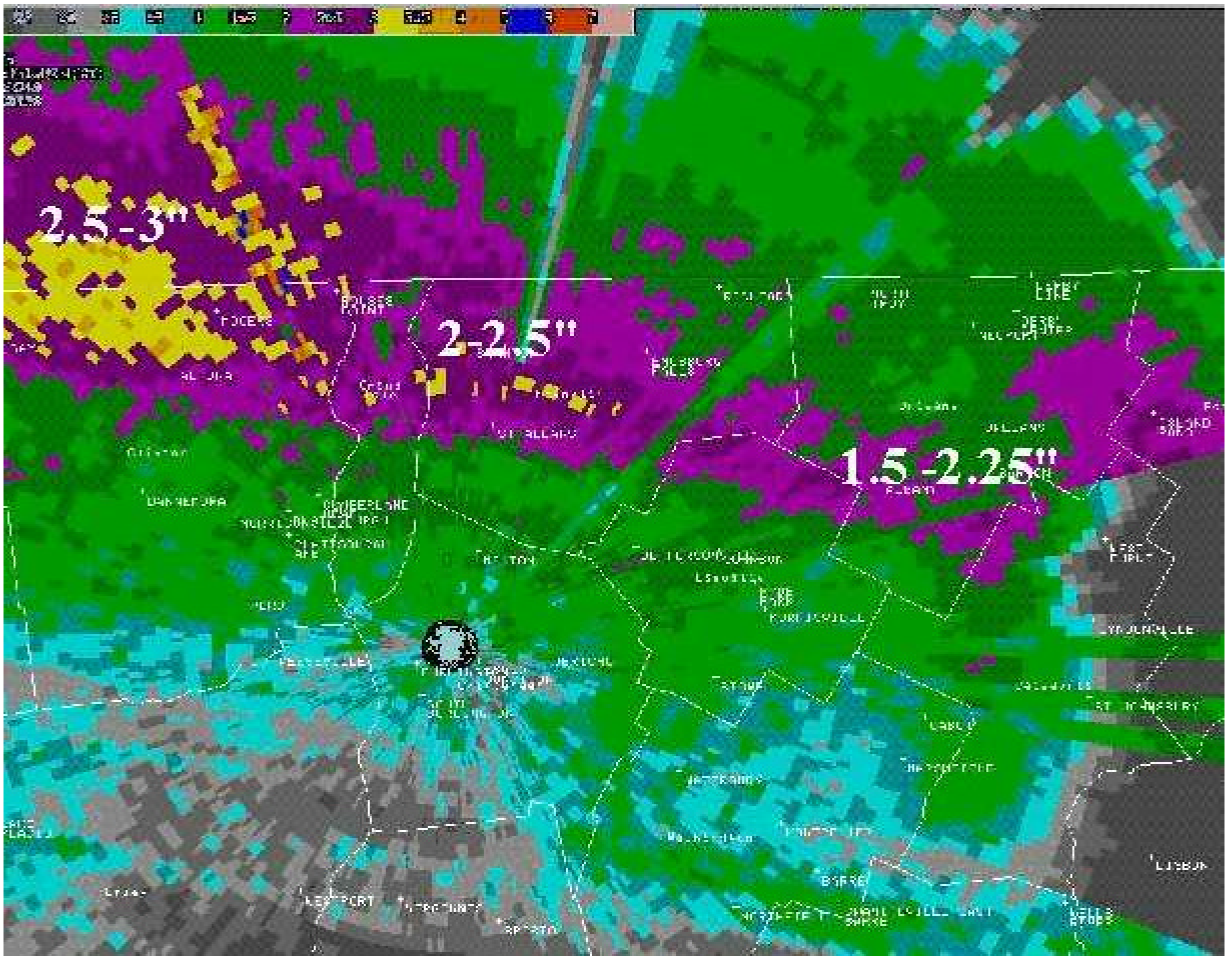


Fig. 6 NWS Burlington's WSR-88D (KCXX) Storm Total Precipitation product at 0400 UTC 12 June 2002. Overlain (white) is the range of storm total precipitation amounts.

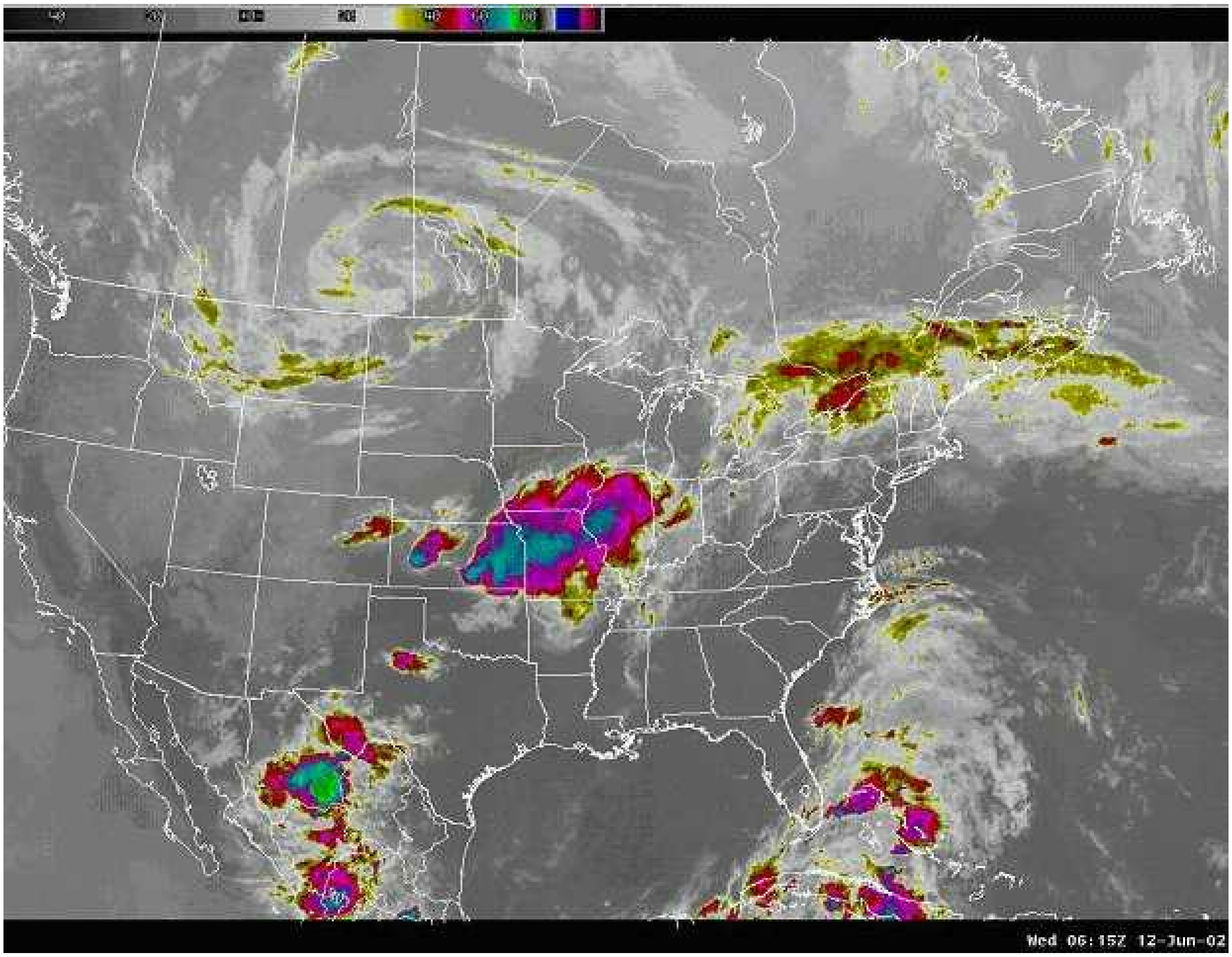


Fig. 7 0600 UTC 12 June 2002 Infrared Satellite picture depicting developing colder cloud tops across southern Ontario, southern Quebec and northern New York.

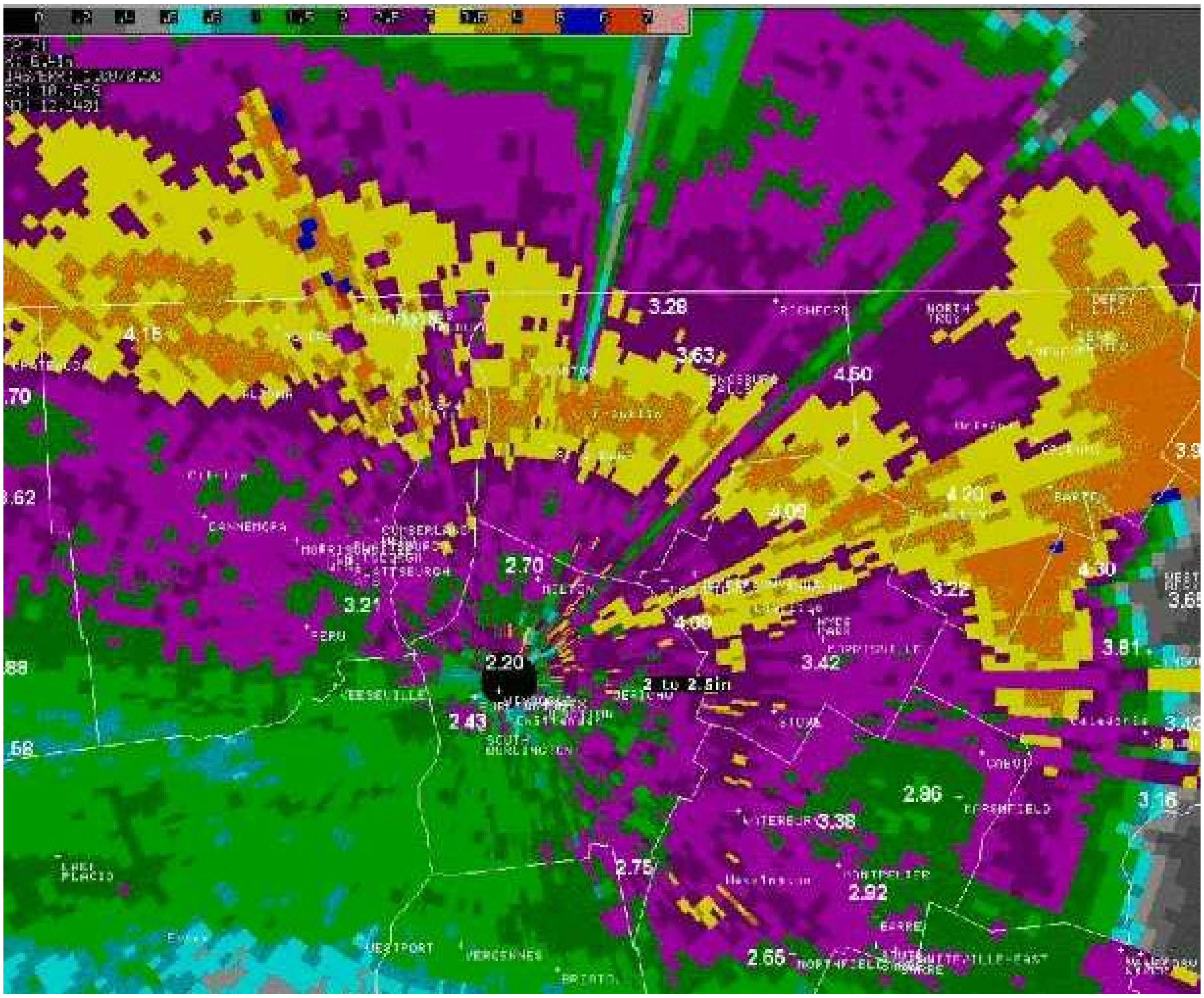


Fig. 8 NWS Burlington's WSR-88D (KCXX) Storm Total Precipitation product for the event, ending 1400 UTC 12 June 2002. Plotted values (white) are storm total observed rainfall in inches.


Fig. 9 USGS Discharge graph for the East Branch of the Passumpsic River at East Haven, VT.