4.4 AN EXPERIMENT IN SUBJECTIVE PROBABILISTIC QUANTITATIVE PRECIPITATION FORECASTING: FORECASTS AND VERIFICATION DURING THE ELBOW 2001 FIELD STUDY

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1. INTRODUCTION

The Effects of Lake Breezes on Weather (ELBOW) 2001 was a field experiment conducted from May 1 to August 31, 2001 in southwestern Ontario. The project was a collaborative effort of the Meteorological Service of Canada, York University, University of Western Ontario and University of Guelph - Ridgetown College. Other contributing agencies were The Weather Network and the US National Weather Service. The primary objectives of the experiment were to learn more about how lake breeze fronts interact with themselves and synoptic-scale weather features to initiate and enhance convective storms, and to evaluate and improve current short-range forecasting of the occurrence and behavior of lake breeze fronts.

The ELBOW 1997 field study (King and Sills, 1998) and other works (Murphy, 1991; Clodman and Chisholm, 1994; Sills and King, 1999) identified that many excessive rainfall producing quasistationary Mesoscale Convective Systems (MCS) in southwestern Ontario are largely governed by the development and propagation effects of lake breeze boundaries. Previous research has also demonstrated the value and merit of Probabilistic Quantitative Precipitation Forecasts (PQPF) as guidance for flood forecasting and risk management in small to medium sized watersheds (Krzysztofowicz, 1998).

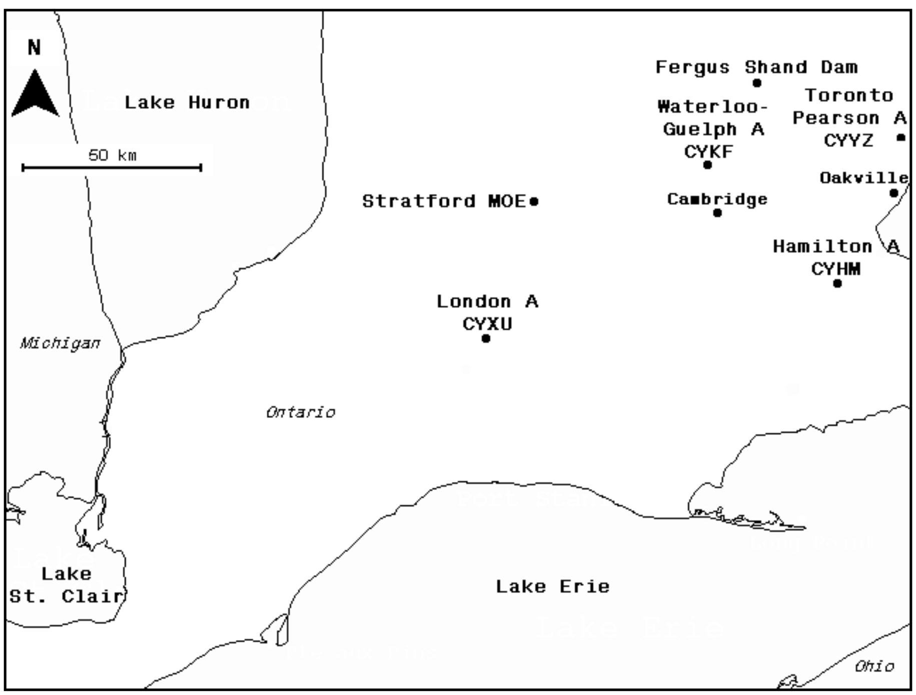

Figure 1. Map of southwestern Ontario showing PQPF point forecast locations.

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The Canadian Weather Research Program (CWRP) has identified QPF as an important area for meteorological research. ELBOW provided a unique opportunity to test the utility of subjective PQPF for a few selected locations within the ELBOW field study domain. The study area is shown in Figure 1.

This paper provides a description of the experimental PQPF products that were issued for ELBOW along with some preliminary verification results and a case example. Suggestions for operational guidance that could be useful to meteorologists in the production of PQPF products are also presented.

2. DESIGN OF THE SUBJECTIVE PQPF

The design of the PQPF experiment was purposely kept simple. The goal was to maintain the balance between the design of a useful PQPF and the ability to easily verify the forecasts. Potential forecast sites were chosen from a list of stations that observe hourly precipitation amounts. Three of the six stations selected were airport sites where synoptic reports are routinely produced. The probabilistic forecast routine was then

EXPERIMENTAL ELBOW QPF DISCUSSION AND RAINFALL EXCEEDENCE PROBABILITIES ISSUED AT 4:15 AM EDT SUNDAY 22 JULY 2001.

OVERVIEW...
DIFFLUENT UPPER RIDGE AT 500 MB EXTENDED FROM CENTRAL OKLAHOMA INTO THE EASTERN DAKOTAS AT 00Z. LIGHT UPPER-LEVEL FLOW OVER THE GREAT LAKES REGION. A CLUSTER OF STRONG THUNDERSTORMS OVER EASTERN UPPER MICHIGAN WAS ASSOCIATED WITH THE ENHANCED LIFTING FROM THE LEFT EXIT REGION OF A HIGH-LEVEL JET STREAK APPROACHING THE WESTERN UPPER GREAT LAKES. THESE STORMS SHOULD BEGIN TO MOVE TOWARDS THE SOUTH SOUTHEAST AND WEAKEN BY SUNRISE AS THEY MOVE AWAY FROM THE FAVORABLE HIGH-LEVEL DIVERGENCE AND TOWARDS A MORE STABLE AIRMASS. AREA OF PRECIPITATION ASSOCIATED WITH A LOW-LEVEL PLUME OF HIGH THETA-E AIR HAS MOVED NORTHEASTWARD ACROSS LAKE ERIE EARLY THIS MORNING. THE SHOWERS HAD DEVELOPED ALONG THE NORTHERN EDGE OF THE HIGH THETA-E AIR TO THE SOUTHWEST OF HAMILTON. THESE SHOWERS WILL MOVE ACROSS THE NIAGARA PENNINSULA AND DISSIPATE BY DAYBREAK.

MODELS SEEM TO BE IN SOMEWHAT BETTER AGREEMENT THIS MORNING. WITH THE EXCEPTION OF THE OPERATIONAL GEM...ALL SOLUTIONS BRING PRECIPITATION TO SOUTHWESTERN ONTARIO DURING THE DAYLIGHT HOURS OF TODAY. CAPE WILL APPROACH 2000 J/KG THIS AFTERNOON ACROSS THE REGION. LIGHT SOUTHWESTERLY SURFACE WINDS SHOULD RESULT IN A COMBINED LAKE-BREEZE BOUNDARY BECOMING ESTABLISHED FROM NEAR SARNIA UP ACROSS THE EXETER AND FERGUS AREAS BY NOON. UPPER-LEVEL JET STREAK APPRAOCHING UPPER MICHIGAN EARLY THIS MORNING SHOULD DIVE SOUTHEASTWARD LATER TODAY. THIS WILL PUT THE ELBOW STUDY AREA UNDER THE LEFT EXIT OF THE JET ALTHOUGH THE ASSOCIATED UPPER-LEVEL DIVERGENCE MAY BE WEAK DUE TO THE ANTICYCLONIC CURVATURE OF THE JET STREAK. THE INCREASE IN THE UPPER LEVEL WINDS WOULD ALSO RESULT IN AN INCREASE IN MEAN WINDS..MEANING THAT CELLS WILL NOT BE AS SLOW MOVING AS THEY HAVE BEEN THE LAST FEW DAYS. WILL GO WITH HIGH POPS AND HIGH EXCEEDENCE PROBABILITIES FOR TODAY SINCE THE PRECIPITABLE WATER IS EXPECTED TO BE AROUND 40 MM AND K-INDICES FROM 32 TO 36 C SUGGESTS POTENTIAL FOR HEAVY DOWNPOURS. FORECASTED CORFIDI VECTORS NORTHWEST 6 TO 11 KNOTS AT ALL SITES THIS AFTERNOON. IF CONVECTION CAN BECOME ORGANIZED INTO AN MCS LATER THIS AFTERNOON...STORMS COULD BE CAPABLE OF PRODUCING SOME 50+ MM 6-HOUR AMOUNTS LOCALLY.

EXCEEDENCE PROBABILITIES 12Z - 18Z SUNDAY 22 JULY 2001.

STATION	TR	5MM	10MM	25MM	50MM
LONDON A CYXU	60%	30%	5%	1%	<1%
STRATFORD MOE	60%	30%	5%	1%	<1%
FERGUS SHAND DAM	70%	40%	10%	2%	<1%
WATERLOO-GUELPH A CYKF	60%	30%	5%	1%	<1%
HAMILTON A CYHM	30%	10%	2%	<1%	<1%
TORONTO PEARSON A CYYZ	60%	20%	5%	<1%	<1%

EXCEEDENCE PROBABILITIES 18Z - 24Z SUNDAY 22 JULY 2001.

STATION	TR	5MM	10MM	25MM	50MM
LONDON A CYXU	70%	50%	30%	20%	10%
STRATFORD MOE	80%	60%	30%	20%	10%
FERGUS SHAND DAM	70%	40%	20%	5%	2%
WATERLOO-GUELPH A CYKF	70%	40%	30%	10%	2%
HAMILTON A CYHM	30%	20%	5%	2%	<1%
TORONTO PEARSON A CYYZ	40%	20%	5%	2%	<1%

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Figure 2. Experimental ELBOW PQPF and forecast discussion issued Sunday, July 22, 2001.

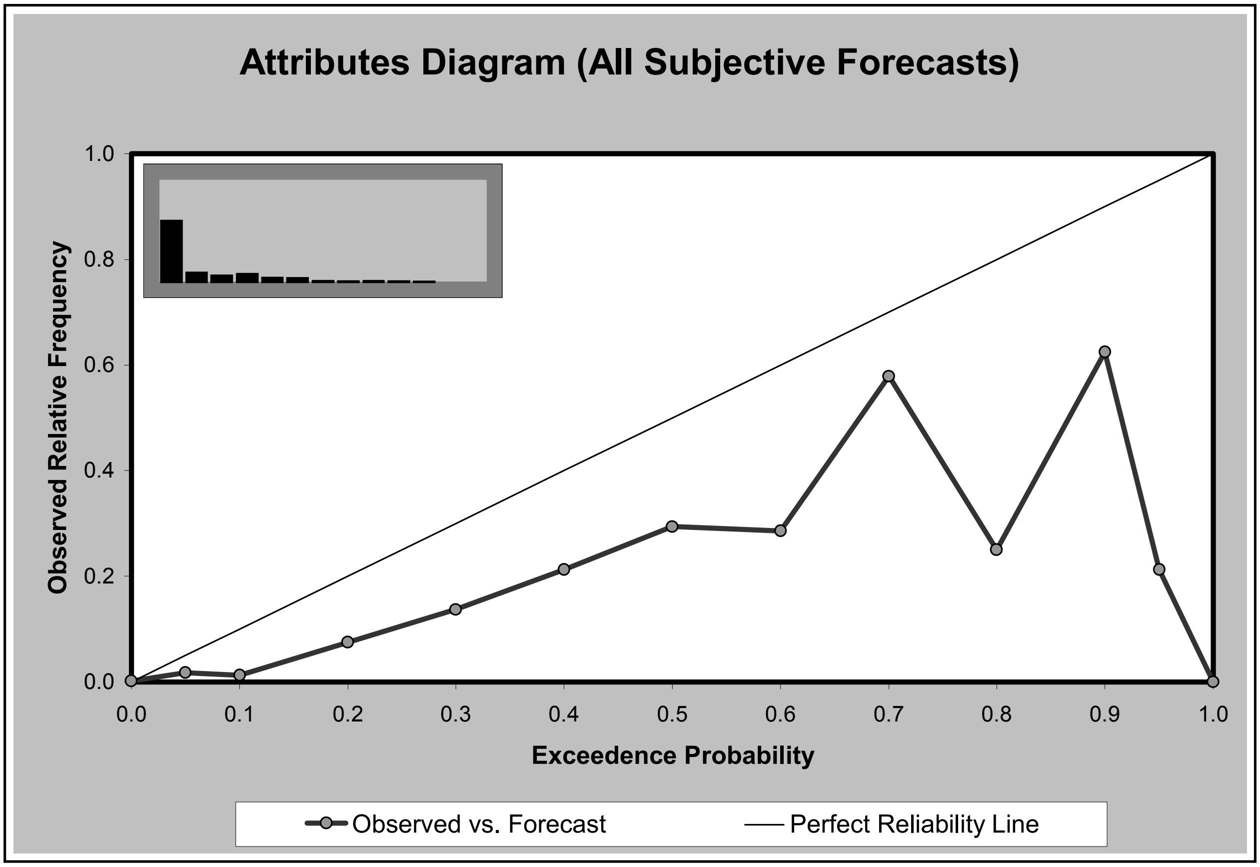

Figure 3. Forecast attributes diagram for all subjective PQPFs issued during the ELBOW 2001 experiment.

designed to use the same time intervals that are reported on the station synoptic reports. A second siting criteria was that each of the forecast sites has relatively long periods of record (i.e., 30 years or more) so that background six-hourly precipitation climatologies could be produced for each site. These data are also used to generate climatological exceedence probabilities to be used as forecast guidance.

The forecasts were usually but not always issued after the 0000 UTC numerical weather prediction (NWP) guidance was available. This was usually after about 0300 UTC. There were two forecast periods for each site having valid periods from 1200 to 1800 UTC, and from 1800 to 2400 UTC. The forecasts were in the form of six-hour exceedence probabilities for five pre-selected rainfall amounts, trace, 5 mm, 10 mm, 25 mm, and 50 mm. Some thought was given to using a design similar to that suggested by Krzysztofowicz (1993), but the decision to use exceedence probabilities was chosen due to its perceived ease of use. A detailed meteorological discussion was also included with each forecast. This was provided not only as guidance for planning purposes, but for the identification of factors considered to be of importance to the forecast along with an impression of the degree of uncertainty or confidence in the forecast. The PQPF product issued on July 22, 2001 is shown in Figure 2.

3. VERIFICATION OF THE PQPF

The experimental subjective PQPF was compared with long-term precipitation climatology and the precipitation observations that had occurred during the ELBOW study period. The PQPF trace exceedence probabilities were also verified against the Model Output Statistics (MOS) from the Global Environmental Multiscale (GEM) Model Regional Configuration of six-hour Probability of Precipitation (POP) forecasts for three sites (i.e., London Airport, Hamilton Airport, and Toronto Pearson International Airport).

Figure 3 is the attributes diagram (Murphy *et al.*, 1985) for the experimental subjective PQPF for all times and all categories. The plotted points in an attributes diagram show the sample relative frequencies as a function of the forecasts. For perfectly reliable forecasts, these paired quantities are equal and fall along the diagonal line labeled "Perfect Reliability Line". Forecast bias can be determined from points that lie on either side of the "Perfect Attributes Line". Figure 3 indicates that there was a fairly strong bias to forecast higher exceedence probabilities than were observed. Although meteorologists provided with this kind of feedback available from attributes diagrams can cognitively adjust their tendency to over/under forecast (Murphy *et al.*, 1985), this experiment was much too short to take advantage of this information.

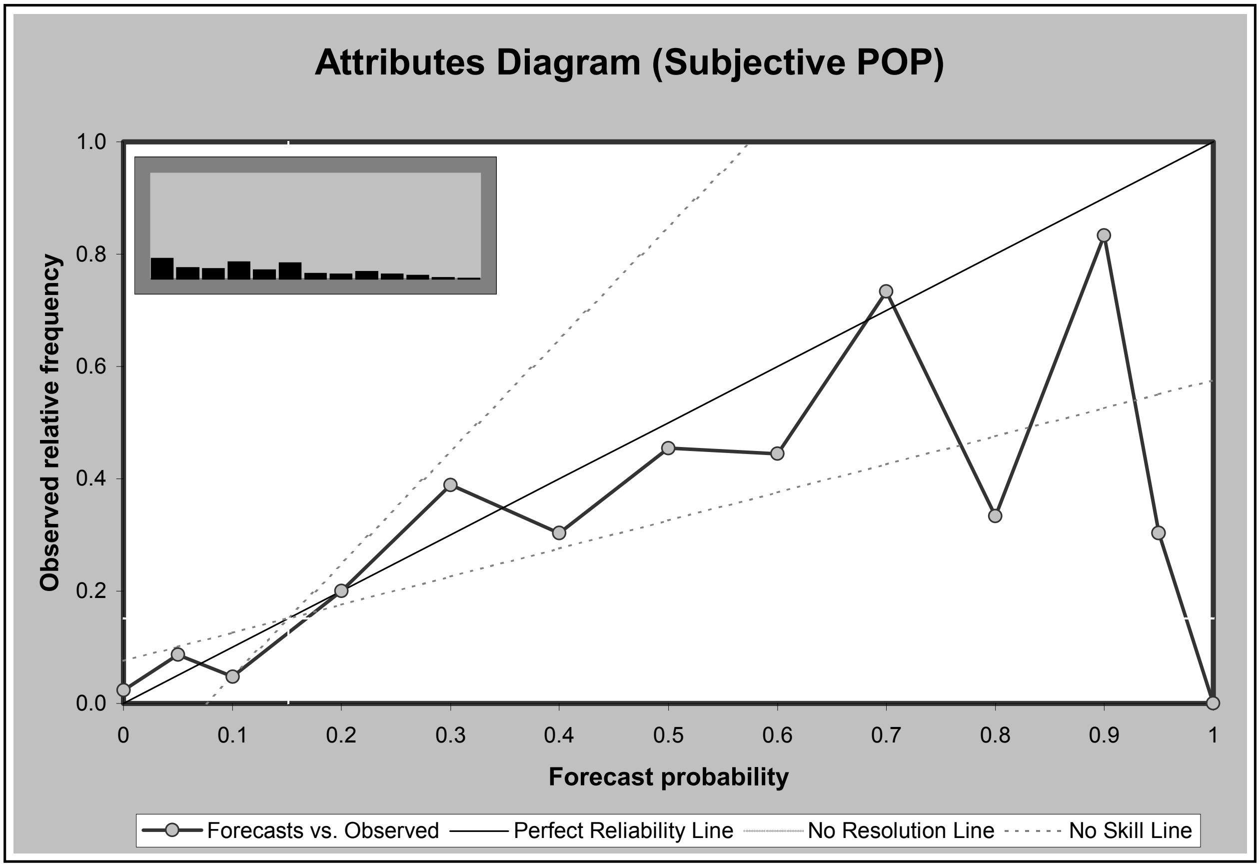

Figure 4. Forecast attributes diagram for all subjective forecasts of trace rainfall exceedence probabilities issued during the ELBOW 2001 experiment.

The subjective POP forecasts represented by PQPF for trace exceedences (Figure 4) show skill, reliability, and good resolution. When compared to the GEM model MOS (Figure 5), the subjective POP forecasts are more skillful, and do not display the underforecasting bias of the objective MOS guidance. The MOS forecasts did not exhibit skill when compared to climatology.

4. A CASE EXAMPLE - 22 JULY, 2001

The summer of 2001 was characterized by lower than normal precipitation in southwestern Ontario. The thirty day 500 HPa geopotential height anomaly analysis from June 16, 2001 through July 15, 2001 (not shown) indicates that a strong positive height anomaly lay over the Rocky Mountain States of the northern United States. It also shows that heights were near normal over most of eastern North America. An anomalously strong upper ridge over the western United States was coupled with a weak upper trough east of the Great Lakes region. The blocking upper ridge had effectively cut-off the northward flow of moisture from the Gulf of Mexico into southern Ontario. Pacific moisture flow around the top of the upper ridge brought occasionally heavy rainfall to the northern United States plain states and to portions of northern Ontario and southern Manitoba.

This blocking pattern began to show signs of breaking down by July 20. A weak surface warm front crossed the eastern Great Lakes during the early morning hours of July 22 with the establishment of a plume of warm and moist air with high low-level equivalent potential temperature across the lower Great Lakes region. A high-level jet streak moved south-southeastward around the upper ridge across the western Great Lakes during the afternoon hours of July 22. These features combined to produce a precipitation efficient environment over the ELBOW region. Although NWP guidance did not explicitly indicate heavy precipitation over southwestern Ontario, there was evidence that deep convection would occur and that there was good potential for the development of locally very high rainfall rates. The main forecast problem was correctly anticipating the development and evolution of the lake breezes that would focus the expected deep convection.

Heavy thunderstorms developed along the Lake Ontario lake breeze front northwest of Lake Ontario. A MCS that that was focused initially along these lake breeze fronts contained thunderstorms that resulted in two lightning deaths near Oakville. The MCS propagated backwards to the juxtaposition of the Lake Erie and Lake Ontario lake breeze fronts to the northwest of Hamilton Airport. This system produced

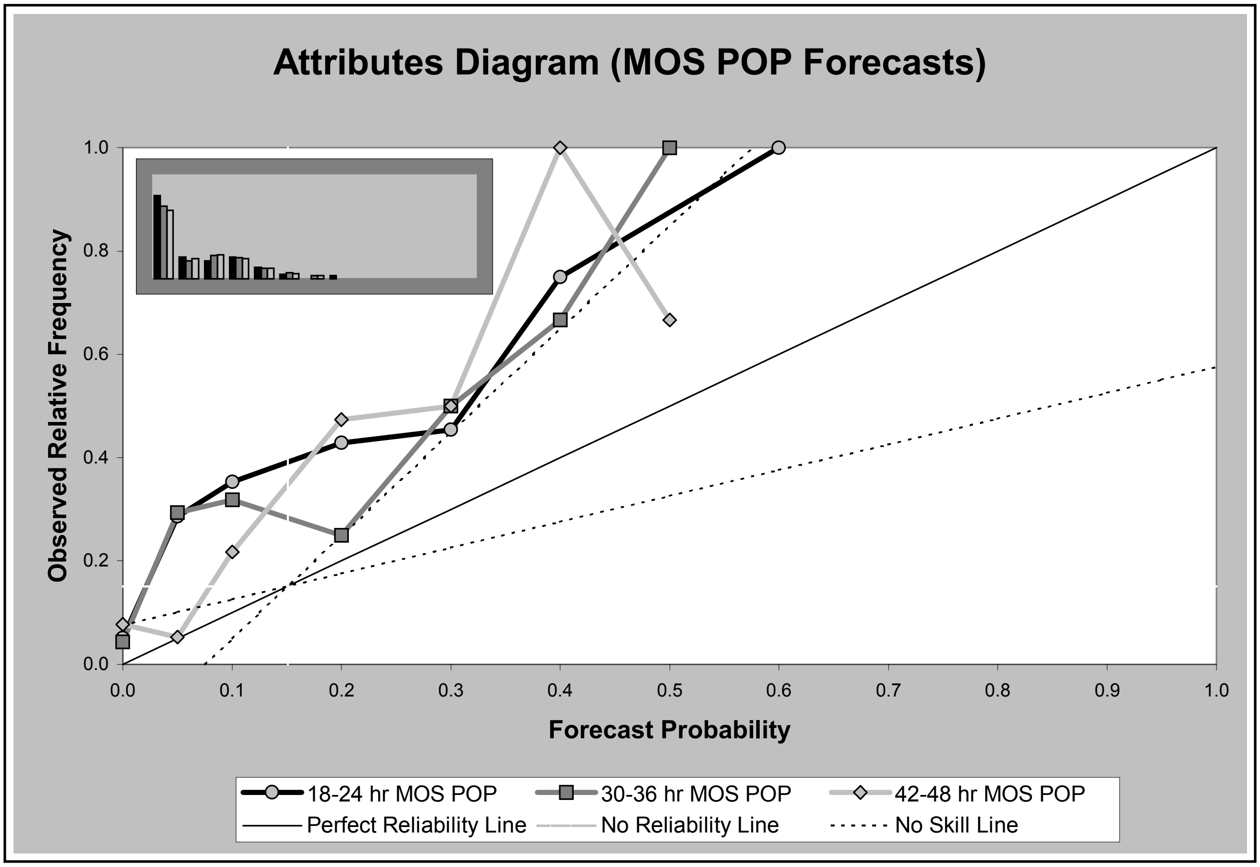

Figure 5. Forecast attributes diagram for all GEM Regional Model MOS 6-hour probability of precipitation forecasts during the ELBOW 2001 experiment.

very high rainfall rates that resulted in local street flooding in Cambridge. The MCS can be seen just west of Lake Ontario on the 2100 UTC GOES-8 visible satellite image from July 22, 2001. None of the forecast sites received rainfall higher than 3.4 mm during the six-hour forecast period from 1800 UTC to 2400 UTC on July 22, which is indicative of the problem of producing accurate point PQPF.

5. DISCUSSION

The PQPF experiment within ELBOW was quite illuminating if not humbling to the forecaster. The routine issuance of PQPF is challenging but the potential benefits of such products to users cannot be understated. Operational meteorologists with the Meteorological Service of Canada (MSC) do not forecast floods, drought, or streamflows. However, users such as the hydrological forecasting community would like to see the best possible QPF products produced routinely. Although good use can be made of reliable and well-resolved deterministic QPF products, it is the quantification of the forecast uncertainty inherent in probabilistic forecasts that is of the most utility to streamflow forecasters. Reliable PQPFs contain all the information required by decision makers to make optimal decisions (Murphy, 1991). It can also be shown that the value of probabilistic forecasts equals or exceeds that of categorical forecasts for all users.

One problem that was encountered in the routine production of PQPF was the lack of useful forecast guidance. While the advent of the routine production of NWP ensemble forecasts in the recent past offers some hope, the guidance needs to be increased in both spatial and temporal resolution to be of use to PQPF forecasters. Krzysztofowicz and Sigrest (1997) describe a procedure to develop local climatic guidance for PQPF and Wilks (1990) showed how PQPF derived from POP and conditional precipitation amount climatologies displayed considerable skill when used in a subjective PQPF experiment. Background climatological exceedence probabilities were developed for the six point locations in ELBOW. However this product was found to have limited usefulness, especially for the higher amounts.

The PQPF methodology that is suggested by Krzysztofowicz (1998) was thought to be complicated and difficult to apply in a field study such as ELBOW. However, it may be better to provide guidance in the form of exceedence fractiles (i.e., $P(W>x_{75})=0.75$; $P(W>x_{50})=0.5$; $P(W>x_{25})=0.25$) since they better represent the range of the forecast uncertainty. This information can be very important to flow forecasters and decision makers.

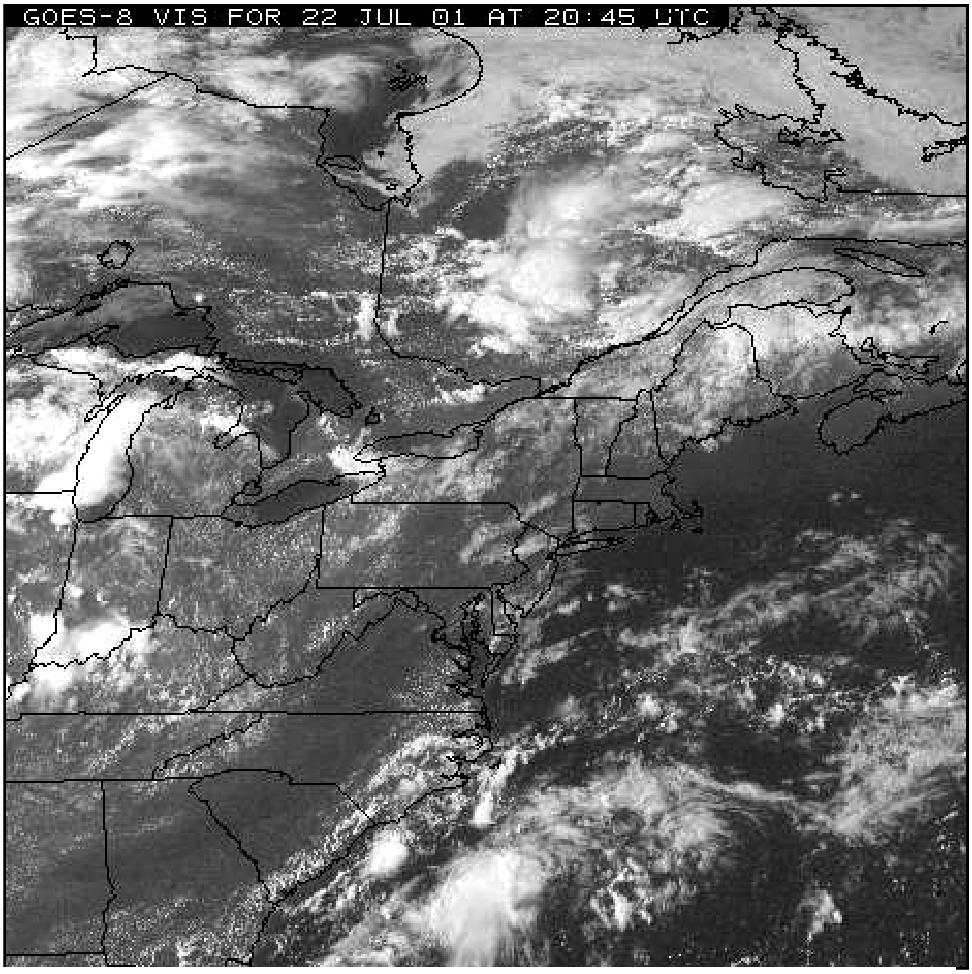

Figure 6. GOES 8 visible satellite image at 2045 UTC July 22, 2001. The mature MCS that produced the heavy precipitation was located just west of Lake Ontario.

The PQPF experiment in ELBOW 2001 was an important initial step in the development of QPF guidance products. More studies of this kind will be crucial to better understand the approach and capabilities of PQPF, and gain recognition within the meteorological community.

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