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ASSESSING THE IMPACT OF COLLABORATIVE RESEARCH PROJECTS ON NWS WARNING PERFORMANCE

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1. INTRODUCTION

In 1990, the Cooperative Program for Operational Meteorological Education and Training (COMET; Spangler et al. 1994) initiated an Outreach Program. The goal of the COMET Outreach Program is to improve local forecast and warning services by providing financial support to colleges and universities for applied mesoscale and synoptic-scale research. To achieve this goal, COMET funds collaborative projects between National Weather Service (NWS) offices and universities (Auciello and Lavoie 1993). These projects generally lead to the adoption of a new forecast technique into operations, an increased understanding of local meteorology, and/or preparation of joint papers and workshops. In addition, many students that have participated in these joint endeavors subsequently have accepted positions within the NWS, where they have made additional contributions toward improving forecast and warning services.

Since the inception of the COMET Outreach program, over 250 collaborative projects have been funded nationwide, involving approximately 90 NWS offices and over 70 different universities. These projects have resulted in the development of numerous new forecast techniques, the publication of hundreds of journal articles and conference preprint papers, and thousands of conference presentations, training seminars, workshop sessions and other presentations at local, regional, and national meetings. In addition, several papers have been written that discuss the short and long term benefits of continued collaborative activities (e.g., Johnson and Spayd 1996 and Grumm et al. 2003), while others such as Hoium et al. (1997) have engaged in joint efforts to examine the NWS warning process. However, to date there have not been any efforts to objectively assess the effect these collaborative research and development activities have had on the abilities of NWS forecasters to issue timely and accurate warnings.

This paper will examine the impact COMET collaborative projects have had on the tornado, severe thunderstorm, flash flood, and winter storm warning programs at participating offices within the NWS Eastern Region (ER). Section 2 will discuss the multitude of factors that influence warning program performance at an NWS Weather Forecast Office (WFO). Section 3 describes the methodology used in this study, with particular emphasis on the approaches employed to attempt to isolate the impacts of the collaborative research activities. The results of the analysis for the 4 warning programs are presented in Section 4. Section 5 will examine the unique case of WFO Raleigh, NC (RAH), where collaborative projects with North Carolina State University (NCSU) have been on-going continuously since the inception of the COMET outreach program. Finally, a summary and concluding remarks are presented in Section 6.

2. FACTORS THAT INFLUENCE WARNING PERFORMANCE

There are numerous factors that can impact the performance of a WFO's warning programs. These factors can affect performance for a specific event, a "season," or they can influence the long-term performance trend. In addition, the impact of certain activities or situations can be limited to an individual WFO, or a small geographic area, while

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other initiatives may have a bearing on performance on a larger scale (e.g., an entire region or nationally). The following discussion does not include every dynamic that might affect performance. Rather, the intent is to highlight some of the more important factors that often come into play, and the scope of the typical impact. It is also important to note that these factors are rarely independent of one another.

2.1. Infusion of New Technologies (Hardware and Software)

The impact of technology infusion is usually realized on a large, often national scale. Deployment of modernized observing and data processing systems such as the WSR-88D (Polger et al. 1994), AWIPS, and new supercomputers at the National Center for Environmental Prediction (NCEP) impact every WFO to some degree. Similarly, software enhancements such as new tornado detection algorithms, or improvements to numerical weather prediction models typically have broad effects on performance. However, local software applications, algorithm refinement, or even regional scale modeling efforts (e.g., Waldstreicher et al. 1998; Mass and Kuo 1998) can have considerable impact on performance at an individual or small group of offices. Regardless of scale, additional applied research and development to refine techniques and methodologies for operational use, plans for integration into operational procedures, and forecaster training are all necessary components for optimizing performance improvements from a technological advance.

2.2. Applied Research and Development

Applied research and development (R&D) occurs on a number of scales. Some efforts involve the development of models, algorithms, and techniques that are designed for national implementation. Other efforts are regional or even local in scope, focusing on the impacts of a very specific topographic feature, for example. Some efforts involve large teams of researchers and developers working collaboratively. These collaborations may take place among individuals within the same laboratory, or center, or they might involve contributors from multiple locations such as universities, field offices, as well as the private sector. Alternatively, some R&D endeavors are conducted primarily by individual investigators. However, there is one key aspect that is common to all applied R&D efforts. For these projects to have an impact on operational performance, the research results must have a path or means to be implemented into forecast and warning operations.

2.3. Changes to Operational Procedures

While technology infusion and R&D activities often drive changes to operational procedures, these changes can be made for other reasons. For example, an office may alter the way tasks and human resources are managed during severe weather events. Examples of alternative task management strategies include: dedicating a forecaster for continual analysis of the mesoscale environment to improve situational awareness during the evolution of an event; utilizing radar teams (multiple individuals working together to interrogate and analyze radar data and make warning decisions); and sectorizing radar operations (assigning different portions of the county warning area to different radar analysts). Other operational changes might include redesign of the operational work space, implementation of new procedures for obtaining ground truth observations, and changes to routine shift duties that also impact workload and task management during hazardous weather situations.

Changes to operational procedures (beyond those driven by the incorporation of new technologies) are most often local in nature (see Parker and Waldron 2002 for an example). However, there are occasions where regional or national factors drive these changes. Examples include the identification and publication of recommended best practices, regional or national changes to service programs, and even fundamental changes to the forecast paradigm, such as the implementation of the Interactive Forecast Preparation System (IFPS) and the National Digital Forecast Database (NDFD; Glahn and Ruth 2003)

2.4. Climate Variability

Past research (e.g., Mullen and Smith 1993) has illustrated how certain patterns or atmospheric flow regimes can impact predictability. Certain climate-scale phenomena such as the El Nino-Southern Oscillation (ENSO) or the North Atlantic Oscillation affect the relative frequencies of regional or local scale phenomena like major winter storms (Patten et al. 2003) or flooding. The relative frequencies of phenomena with varying degrees of predictability have a direct impact on forecaster performance (Roebber 1998). For example, weather regimes that favor supercells as opposed to linear, or non-organized convection tend to result in higher probabilities of detection (PODs) and lead times for tornado warnings. Similarly, moist antecedent conditions caused by extended periods of above normal precipitation often yield improved flash flood verification scores, likely due in part to increased situational awareness.

Impacts of flow regimes on event type and frequencies (and resultant warning performance) are typically evident on local and regional scales. However, if a persistent pattern impacts warning performance in regions where the phenomena of concern are substantially more frequent than the rest of the country, then the national performance scores will be affected. For example, if a pattern results in an unusually higher (lower) occurrence of supercell storms in the central U. S., then national tornado warning scores (as well as scores for individual offices and region-wide) will likely be higher (lower) than expected. The temporal impact of this factor typically matches the time scales of the causative climate phenomena – some are seasonal to a year, while others can last multiple years (e.g., long-tern droughts decreasing flood frequencies).

2.5. External Outreach and Education

The primary impact of external outreach efforts on objective performance measures is through the expansion and training of spotter networks. These spotter networks are critical sources of ground-truth information. However, spotter reports are important not only to support post-event verification and documentation efforts. Wolf (2002) documented how the development and training of spotter networks, and their integration into the warning decision process was important for improving warning performance. These outreach efforts impact performance primarily (although not always exclusively) on a local scale.

2.6. Personnel Issues

Staffing changes at local WFOs can also have an effect on warning performance. Extended periods of reduced staffing, particularly during active weather regimes, can have a negative impact. In addition, the departure of highly experienced forecasters from a staff and subsequent replacement with inexperienced forecasters can also have a detrimental impact (Roebber and Bosart 1996). These personnel factors usually affect individual offices in a sporadic nature, and the impacts are usually only over a season or a year, especially as new forecasters gain experience. The time required for forecasters to gain this experience is to a large extent a function of the frequency of occurrence of specific phenomena. For example, if a WFO experiences winter storms or tornadoes only a couple of times a year, and a new forecaster is not working those particular shifts, then it will take longer to build experience. A recently developed method to more rapidly develop forecaster experience is through the use of the Weather Event Simulator (WES; Magsig and Page 2003).

2.7. Training

Training is the common thread for all of the factors previously discussed. The degree to which new technologies and research results impact forecaster performance is strongly modulated by the amount and quality of the training they receive. Changes to operational procedures also often require staff training. Improving forecasters understanding of climate variability, and how certain weather regimes affect the frequency and morphology of various hazardous events, can result in better situational awareness, which ultimately results in improved warning performance (Wolf and Howerton 2003). The importance of development and training of spotter networks for improving warning performance has also been documented (Wolf 2002). Finally, new staff training and familiarization can have a substantial effect on warning performance.

Training initiatives can be national, regional, or local in scope. The effects of training are evident on the full range of time scales, but the primary impact is usually evident in the long term performance trends.

3. METHODOLOGY

The inter-relationship of the various factors discussed in Section 2 make it very difficult to tie performance changes to a specific cause. Also, it is not possible to analyze the "null case." In most cases, the factor being evaluated involves the forecaster having some new tool, or data, or even knowledge. The problem is that forecasters either have the data or knowledge, or they do not. The question of "What if they did not have the knowledge?" cannot be directly answered.

The approach taken in this study was to attempt to isolate, to the extent possible, the signal in the verification scores that could be attributed to the impact of collaborative research. This was done by attempting to identify a performance baseline for comparison that incorporated as many of the other factors as possible.

This study examined COMET projects involving NWS Eastern Region (ER) offices that were completed between 1995 and mid-2001. COMET supports two primary types of collaborative research projects – Cooperative and Partners projects. Cooperative projects between a NWS office or multiple offices and a university (in a few cases multiple institutions are involved) usually are 2 or 3 years in length, and typically cover a variety of forecasting topics of interest to the various participants, or focus on an in-depth study of a single forecast problem. COMET Partners project are usually 1 year in length, typically involve one NWS forecaster and one university faculty member, rather than a group (as is usually the case with Cooperative projects), and generally focus on a single case study or analysis problem. COMET projects that specifically addressed tornado, severe thunderstorm, flash flood and winter storm warning programs were identified and grouped. The following verification scores were examined for offices involved in these projects: Probability of Detection (POD); False Alarm Ratio (FAR), Lead Time (LT), and the percentage of events with zero lead time (for flash flood events only). Three-year running verification scores were used as a baseline for the study. These 3-year mean scores were used to help minimize impact of short-term factors such as the variability of event frequencies, and therefore smooth out any positive or negative performance "spikes."

Verification scores for the 3 years before the project were compared to the scores for the 3 years following the project**.** For the longer Cooperative projects, the final year of the project was considered part of the post-project, or "after" period. This was done because collaborative project results are typically being incorporated into operations by this point. The initial years of these multi-year projects were considered part of the "before" period. The 1995 to mid-2001 project completion period was used to help ensure that 3 years of post-88D-era data could be used for the "before" scores, and a full 3 years of "after" scores were available. Verification scores for the calendar years 1993 through 2002 were used for the tornado, severe thunderstorm, and flash flood analyses. For the winter storm warnings, data for the 1993-94 through 2002-03 winter seasons were utilized.

Annual verification data for all 23 ER offices were utilized to compute running 3-year mean scores for the entire region for the same study period. The slopes of the long-term trend lines for these regional scores were utilized to generate "expected" 3-year improvement rates. These expected improvements based on the regional trends were then compared to the improvements for the WFOs involved in the collaborative projects. This approach was taken to minimize the impact of national and/or region-wide factors on the assessment. Overall, this appeared to be successful. However, it is very difficult to account for the impact of project results beyond the primary collaborating WFO. It can reasonably be expected that improvements are realized to varying degrees (depending upon the specific problem studied and the subsequent results) at nearby offices, if not across the entire region or nation. It is likely that these broader improvements are lagged to various degrees compared to the verification improvements of the primary collaborating offices.

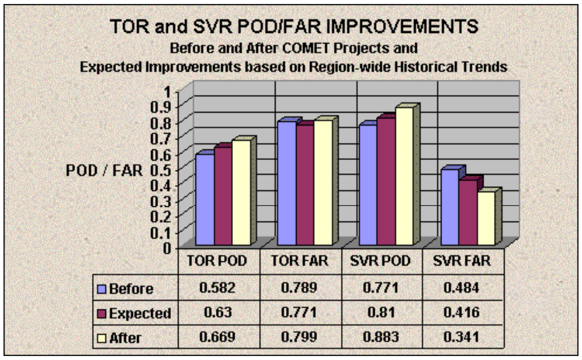
Finally, for each individual project, the improvement noted between the "before" and "after" statistics was compared to the region-wide improvement for the same period of time.

4. RESULTS

Figure 1 depicts the POD and FAR for tornado (TOR) and severe thunderstorm (SVR) warnings for offices involved in COMET projects. The verification scores are for the 3 years before the project, and the 3 years after the projects. An "expected" after score was also computed for each office. These "expected" scores were computed by taking the "before" scores and adding the long-term (1993-2002) mean region-wide 3-year improvement. This is an attempt to estimate what the verification scores might have been without the collaborative research project.

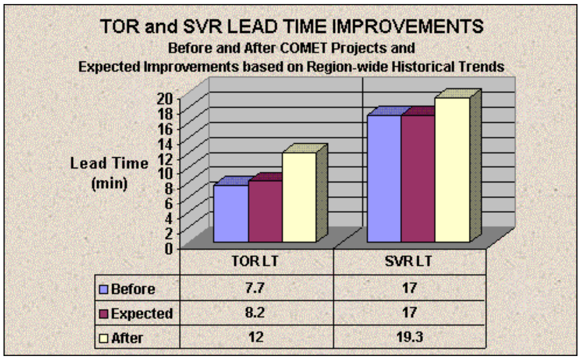
Offices involved in COMET projects experienced roughly twice the rate of improvement for TOR and SVR POD, as well as SVR FAR compared to the region-wide trend (Fig. 1). However, TOR FAR for COMET project offices actually showed a slight decline (e.g., a very small increase in FAR) while the regional performance indicated a minimal improvement (e.g., a slight decrease in FAR).

Figure 2 shows the respective tornado and severe thunderstorm warning lead times. TOR lead times (Fig. 2) for COMET project offices showed considerable improvement in comparison to the regional trend. While the 3-year trend would predict a 0.5 minute improvement, the actual average lead time increased 4.3 minutes, which corresponds to nearly one radar volume scan. Similarly, while the SVR average lead time for the region has shown no change over the long term, offices involved in COMET projects showed a 3-year improvement of 2.3 minutes.



	TOR POD	TOR FAR	SVR POD	SVR FAR
Before	0.582	0.789	0.771	0.484
Expected	0.63	0.771	0.81	0.416
After	0.669	0.799	0.883	0.341

Figure 1. *Tornado warning (TOR) and Severe Thunderstorm warning (SVR) POD and FAR for offices involved in COMET projects related to these phenomena. Verification scores indicated are for: the 3 years before the project (blue), the 3 years after the project (yellow), and the expected scores for the 3 years after the project (magenta) based upon the long term regional performance trend.*



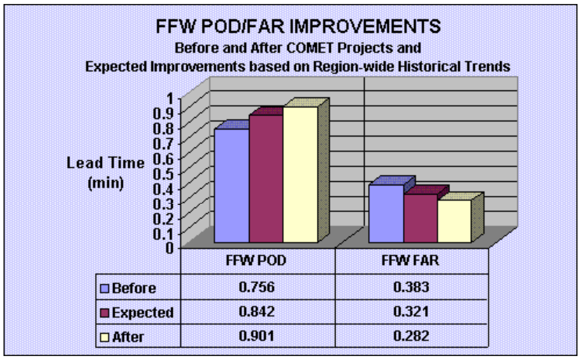
	TOR LT	SVR LT
Before	7.7	17
Expected	8.2	17
After	12	19.3

Figure 2. *Same as Figure 1 except for TOR and SVR Lead Time.*

Figure 3 depicts the POD and FAR improvements for flash flood warnings (FFW). Both the FFW POD and FAR show considerably greater improvements (roughly 60-70%) for COMET project offices than what would be expected based on the region-wide trends.

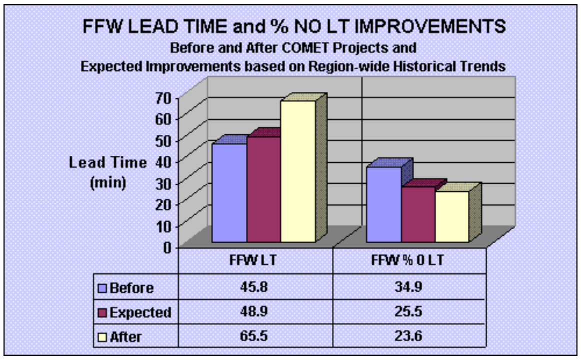
Figure 4 shows the lead time improvements, as well as the percentage of time FFWs are issued with no lead time. This score is useful because flash floods are long duration events (relative to tornadoes and severe thunderstorms). As a result, it is possible (and desirable from a service standpoint) to issue an FFW upon receipt of a flooding report. In such a situation, the warning would be considered a "hit," resulting in a higher POD, although the lead time would be considered zero. The percentage of zero lead time is a measure of the frequency the public received no advance warning (e.g., missed events combined with warnings issued after the flooding began).

FFW lead times for COMET project offices improved substantially more than the Eastern Region as a whole (Fig. 4). The percentage of zero lead time events also dropped more than would be expected from the long term regional trend.



	FFW POD	FFW FAR
Before	0.756	0.383
Expected	0.842	0.321
After	0.901	0.282

Figure 3. *Same as Figure 1 except for Flash Flood warnings (FFW).*

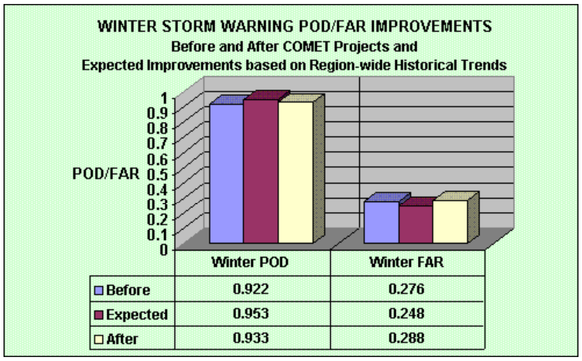


	FFW LT	FFW % 0 LT
Before	45.8	34.9
Expected	48.9	25.5
After	65.5	23.6

Figure 4. *Same as Figure 1 except for FFW Lead Time (LT) and the percentage of flash flood events with no lead time.*

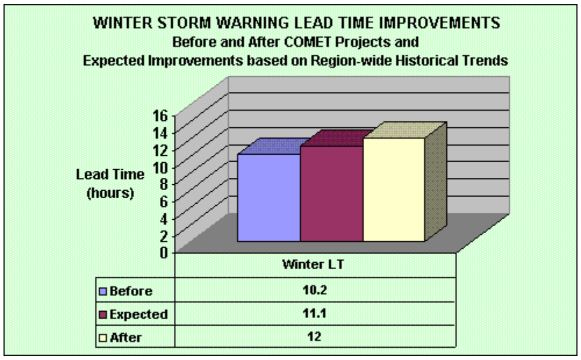
The POD and FAR scores for winter storm warnings are shown in Figure 5. The POD for COMET project offices shows a small improvement for the 3 years following completion of the projects, while the FAR is slightly higher. Both the POD and the FAR scores did not improve as much as the regional trend. However, the initial winter storm warning POD for the COMET project offices was .922. This value is not only very high, but it is considerably higher than the overall regional POD (3-year scores ranged from .814 to .900 during the study period). Similarly, the initial FAR for COMET offices was .276, while overall ER 3-year FAR's for the study period ranged from .300 to .397). This indicates that the WFOs involved in winter storm related COMET projects were among the top performing offices to begin with.

Figure 6 depicts the improvement in winter storm warning lead times. COMET project offices improved their lead times at double the rate of the region as a whole. Thus, the offices involved in these collaborative projects were able to continue to improve their already very high PODs, and substantially improve their lead times without substantially increasing their FARs.



	Winter POD	Winter FAR
Before	0.922	0.276
Expected	0.953	0.248
After	0.933	0.288

Figure 5. *Same as Figure 1 except for Winter Storm warnings.*



	Winter LT
Before	10.2
Expected	11.1
After	12

Figure 6. *Same as Figure 1 except for Winter Storm warning lead time.*

In summary, the COMET project offices showed considerable improvement in lead times for all 4 warning programs compared to expectations based on the regional trends. Enhanced improvements were also noted for POD. Results for FAR were not as conclusive.

Figures 1-6 quantitatively compared 3-year improvements for offices involved in COMET collaborative research to the long term Eastern Region-wide improvement trend. An alternative way to examine the impact of these projects is to compare the 3-year performance change associated with each individual project to the region-wide improvements for the same time period. Table 1 shows the results of this comparison.

The comparisons for the individual projects in Table 1 reveal similar results to the trend analysis. Offices involved in COMET projects consistently showed greater improvements in POD and lead time than the region as a whole, while FAR improvements did not indicate any difference.

5. THE IMPACTS OF LONG-TERM COLLABORATIVE RESEARCH EFFORTS: THE CASE OF WFO RALEIGH

WFO Raleigh, NC (RAH) has a long history of collaboration with North Carolina State University (NCSU; Lee et al. 1992). At least one collaborative research project has been in progress between the two facilities since the inception of the COMET Outreach Program. From January 1991 through 2000, 3 Cooperative Projects, 3 Partners Projects, and 1 Graduate Fellowship were completed. Since 2000, one Collaborative Science, Technology, and Applied Research (CSTAR) Program project has been completed, and a second CSTAR project is underway. (More information about the CSTAR program can be found at: http://www.nws.noaa.gov/om/cstar.htm). In addition, WFO RAH and NCSU have defined a process by which research findings are integrated into operations (Keeter 2002). As a result, WFO RAH presents a unique "laboratory" to examine the impact of long-term collaborative research activities.

PROBABILITY OF DETECTION (POD)

	# of COMET Projects With **WFO Greater Improvement**	# of COMET Projects With **ER Greater Improvement**	# of COMET Projects With **No Difference in Improvement**
Tornado Warnings	**3**	**2**	**1**
Severe Tstm Warnings	**6**	**1**	**0**
Flash Flood Warnings	**5**	**1**	**0**
Winter Storm Warnings	**4**	**3**	**0**

FALSE ALARM RATIO (FAR)

	# of COMET Projects With **WFO Greater Improvement**	# of COMET Projects With **ER Greater Improvement**	# of COMET Projects With **No Difference in Improvement**
Tornado Warnings	**2**	**4**	**0**
Severe Tstm Warnings	**3**	**4**	**0**
Flash Flood Warnings	**3**	**3**	**0**
Winter Storm Warnings	**3**	**3**	**1**

LEAD TIME

	# of COMET Projects With **WFO Greater Improvement**	# of COMET Projects With **ER Greater Improvement**	# of COMET Projects With **No Difference in Improvement**
Tornado Warnings	**5**	**1**	**0**
Severe Tstm Warnings	**5**	**1**	**1**
Flash Flood Warnings	**4**	**1**	**1**
Winter Storm Warnings	**4**	**3**	**0**

Table 1. *Number of WFOs involved in COMET projects that showed greater or lesser 3-year improvements in warning program verification scores compared to all of ER for: a) POD; b) FAR; and c) Lead Time.*

Figures 7 and 8 show the RAH and Eastern Region TOR 3-year mean performance scores from 1990-92 through 2000-02. All of the scores (especially the POD, and to a lesser extent the lead time) for both RAH and Eastern Region show a distinct jump in improvement during the mid-1990s. This is likely due to the deployment of the WSR-88D (Polger et al. 1994). It is interesting to note that the regional scores appear to level off after this WSR-88D associated performance increase. However, WFO RAH continued to show substantial improvements in POD and lead time, with both scores rising to well above the region-wide levels during the last 5 years.

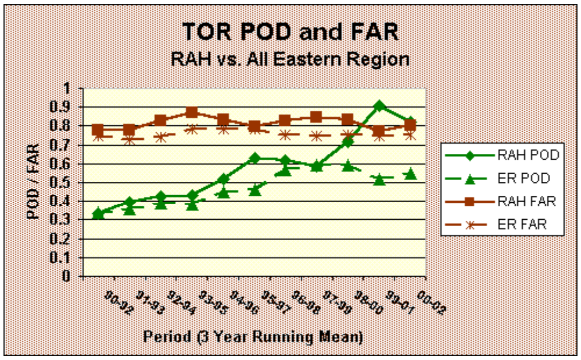


Figure 7. *3-year running mean TOR POD and FAR for WFO RAH (solid) and all of Eastern Region (dash).*

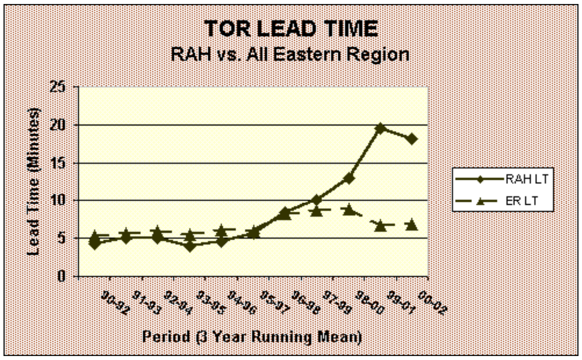


Figure 8. *Same as Figure 7 except for TOR Lead Time.*

Figure 9 depicts the SVR POD and FAR scores. Again, both scores show a substantial surge associated with WSR-88D deployment, with a subsequent leveling off in the regional performance scores. During the early 1990s, WFO RAH's SVR POD and FAR were consistently below the regional scores. However, during the study period, RAH's scores improved at a greater rate than the region as a whole as evidenced by the crossing of the performance curves. RAH's POD is now consistently higher and the FAR is lower (or equal to) the regional scores.

SVR lead times across Eastern Region have remained roughly constant over the long term, especially since WSR-88D deployment (Fig 10). However, WFO RAH forecasters have increased their SVR lead times by roughly 5 minutes (which corresponds to approximately one WSR-88D volume scan), and are now slightly higher than overall Eastern Region levels.

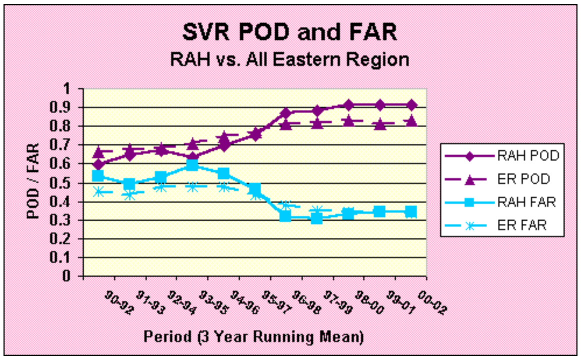


Figure 9. *Same as Figure 7 except for SVR POD and FAR.*

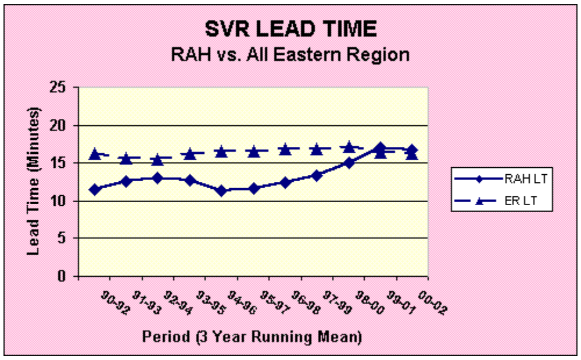


Figure 10. *Same as Figure 7 except for SVR Lead Time.*

Figures 11 and 12 show the FFW scores for RAH and Eastern Region. Again, large improvements in performance associated with the WSR-88D are evident. What is also apparent is the higher rate of improvement in the WFO RAH scores compared to the regional scores. All four sets of curves cross with WFO RAHs performance being initially below the regional average, but improving to values that are above the overall regional performance.

The impact of climate variability is also evident in Figure 12. The late 1990s was a very wet period across much of the region, but especially across the Carolinas where several tropical systems made landfall, causing extensive flash flooding. During 2000 the pattern changed, resulting in an extended period of below normal precipitation. By 2001 and 2002, much of Eastern Region experienced drought, with some of the driest conditions across the Carolinas. Increased lead times during the wet period and decreased lead times during the dry period are evident in both the RAH, and to a lesser but still substantial extent, the regional scores.

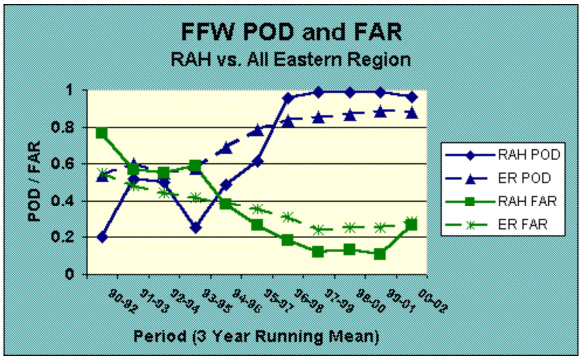


Figure 11. *Same as Figure 7 except for FFW POD and FAR.*

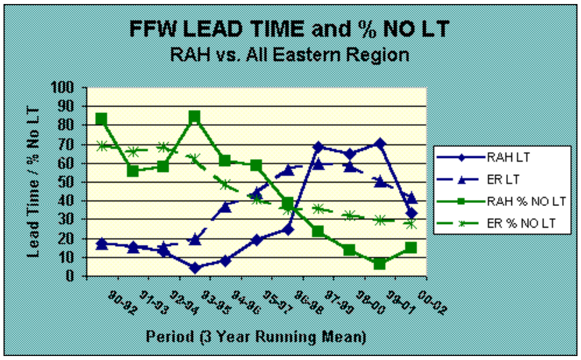


Figure 12. *Same as Figure 7 except for FFW Lead Time.*

As shown in Figure 13, WFO RAH historically has an extremely high POD for their winter storm warnings. Even though RAH has consistently achieved PODs exceeding 0.9, an improving long term trend is still evident. The substantial drop in the 2000-01 through 2002-03 3-year POD is primarily due to one event during the winter of 2002-2003 when a decision was made to downgrade winter storm warnings to advisories (K. Keeter, personal communication). Warning criteria was subsequently reached; therefore this is technically considered a missed event, even though from a service standpoint the public did receive advance warning. Since the previous 2 winters had lower than normal event counts, and climatologically RAH experiences fewer winter storms than areas further north, this one event had a substantially large impact on even the 3-year score.

WFO RAH has substantially improved their winter storm warning lead time during this period of collaboration (Fig. 14). Historically, RAH's average lead times lagged the regional mean. During the last 5-6 years, this gap has closed, with RAH's average winter storm warning lead time for the last 3 years actually exceeding the regional mean, despite the missed event discussed earlier. This is particularly noteworthy because of RAH's proximity to a favored region for secondary cyclogenesis, and the resultant winter weather forecasting complications (Gurka et al. 1995; Keeter et al. 1995). Regions further north such as New England often have time to observe the evolving cyclogenesis before the heavy precipitation reached these areas, facilitating longer warning lead times.

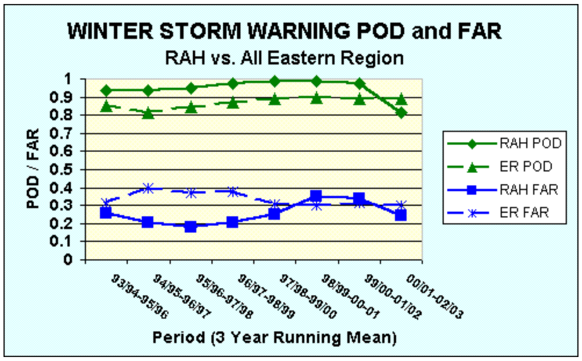


Figure 13. *Same as Figure 7 except for Winter Storm POD and FAR.*

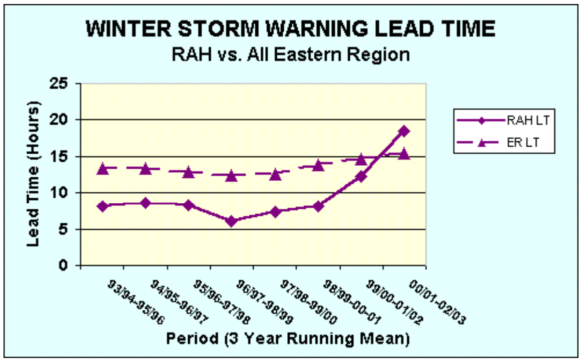


Figure 14. *Same as Figure 7 except for Winter Storm Lead Time.*

6. DISCUSSION AND SUMMARY

There is a common overall message evident in all of the results of this study. Warning program verification scores for offices involved in COMET collaborative research activities appear to improve at a greater rate than the overall Eastern Region performance. The enhanced improvement was most substantial for warning lead times. PODs also showed increased improvement rates, although the degree varied for each warning program. FARs showed small improvement enhancements for some types of warnings, but in other cases there a slight decrease in the rate of improvement compared to the entire region. There are two possible reasons for this lack of FAR improvement. First, the vast majority of research efforts tend to be focused on improving the actual detection/prediction of a certain phenomenon. Less attention is typically paid to non-prediction. Another possibility is that it takes some time and experience for forecasters to fully understand how to optimally apply a new technique or conceptual model. Enthusiastic forecasters learning a new technique sometimes over-apply it, resulting in extra false alarms. This should decrease over time, although how long is not known, and likely varies with each technique as well as the frequency of the particular event (e.g., how fast forecasters can gain experience and advance along the "learning curve"). Perhaps these results would have been different if a longer post-project period was evaluated.

The results of this study also indicate that certain performance metrics might be more responsive to the operational application of research results, while other metrics may have greater sensitivity to other factors. For example, tornado warning PODs may be more responsive to technology improvements (e.g., hardware enhancements such as dual polarization, or software enhancements like new processing or feature identification algorithms). These technology improvements directly impact the radar's ability to *detect* the phenomena. However, to improve lead times, forecasters must be able to recognize the detection and respond sooner. This improved warning decision process requires increased situational awareness, improved knowledge of the morphology of the tornadoes, and enhanced abilities to most effectively apply the radar data. This appears to be illustrated in Figures 1 and 2 and Table 1 where substantial lead time improvements are noted. The application of results from collaborative research activities (and the associated training) enabled forecasters at those WFOs to more rapidly recognize what the radar was detecting, resulting in earlier decisions to warn, and subsequently yielding the considerably longer lead times. Additional study is needed to further examine and quantify this relationship.

7. ACKNOWLEDGEMENTS

Thanks to Ken Johnson, Joshua Watson, David Novak, Larry Lee, Kermit Keeter and the many other colleagues across the NWS Eastern Region who have participated in many valuable discussions on this topic.

REFERENCES

Auciello, E. P. and R. L. Lavoie, 1993: Collaborative research activities between National Weather Service operational offices and universities. *Bull. Amer. Meteor. Soc.*, **74**, 625–630.

Glahn, H. R. and D. P. Ruth, 2003: The new digital forecast database of the National Weather Service. *Bull. Amer. Meteor. Soc.*, **84**, 195–201

Grumm, R.H., P. Knight, and J. Diercks, 2003: The benefits of a nine year partnership between the National Weather Service and Penn State University. *Preprints, 12th Symposium on Education*, Amer. Meteor, Soc., Long Beach CA, 6 pp.

Gurka, J. J., E. P. Auciello, A. F. Gigi, J. S. Waldstreicher, K.K, Keeter, S. Businger, and L .G. Lee, 1995: Winter weather forecasting throughout the Eastern United States. Part II: An operational perspective of cyclogenesis. *Wea. Forecasting,* **10**, 21–41.

Hoium, D. K., A. J. Riordan, J. Monahan, and K. K. Keeter, 1997: Severe thunderstorm and tornado warnings at Raleigh, North Carolina. *Bull. Amer. Meteor. Soc.*, **78**, 2559–2575.

Johnson, V. C., and L. E. Spayd, 1996: The COMET Outreach Program: Cooperative research to improve operational forecasts. *Bull. Amer. Meteor. Soc.*, **77**, 2317–2332.

Keeter, K., 2002: WFO Raleigh collaborative research - A five step process. [Available at: http://www2.ncsu.edu/eos/service/pams/meas/sco/research/nws/fivestep/]

Keeter, K. K., S. Businger, L. G. Lee, and J. S. Waldstreicher, Jeff S. 1995: Winter weather forecasting throughout the Eastern United States. Part III: The effects of topography and the variability of winter weather in the Carolinas and Virginia. *Wea. Forecasting,* **10**, 42–60.

Lee, L. G, K. K. Keeter, S. Businger, and A. J. Riordan, 1992: Geography-related forecast problems in the southeastern United States and a joint North Carolina State University – National Weather Service effort to improve the understanding and prediction of these events. *Preprints, Symposium on Wea. Forecasting*, Amer. Meteor, Soc., Atlanta, GA., 166-172

Magsig M.A. and E.M. Page, 2003: Weather event simulator implementation and future development *Preprints, 20th Int. Conf. on Interactive Info. Processing Sys. (IIPS) for Meteor., Ocean., and Hydro.,* Long Beach CA., Amer. Meteor. Soc., 3 pp.

Mass, C. F., and Y-H Kuo, 1998: Regional real-time numerical weather prediction: Current status and future potential. *Bull. Amer. Meteor. Soc.*, **79**, 253–263.

Mullen, S. L. and B. B. Smith, 1993: The dependence of short-range surface cyclone forecasts on the large-scale circulation: A preliminary assessment. *Wea. Forecasting,* **8**, 235–247.

Parker, S. S., and H. Waldron, 2002: Dramatically improving warning services – One offices experience. *Preprints, 21st Conf. on Severe Local Storms*, Amer. Meteor. Soc., San Antonio, TX., 2 pp.

Patten, J. M., S. R. Smith and J. J.O'Brien, 2003: Impacts of ENSO on snowfall frequencies in the United States. *Wea. Forecasting,* **18**, 965–980.

Polger, P. D., B. S. Goldsmith, R. C. Przywarty, and J. R. Bocchieri, 1994: National Weather Service warning performance based on the WSR-88D. *Bull. Amer. Meteor. Soc.,* **75**, 203–214.

Roebber, P. J., 1998: The regime dependence of degree day forecast technique, skill, and value. *Wea. Forecasting*, **13**, 783–794.

Roebber, P. J., L. F. Bosart, 1996: The Contributions of education and experience to forecast skill. *Wea. Forecasting*, **11**, 21–40.

Spangler, T. C., V. C. Johnson, R. L. Alberty, B. E. Heckman, L. Spayd, and E. Jacks, 1994: COMET: An Education and training program in mesoscale meteorology. *Bull. Amer. Meteor. Soc.*, **75**, 1249-1259.

Waldstreicher, J. S, E. A. Mahoney, R. J. Ballentine, D. Schleede, J. Maliekal, and S. J. Colucci, 1998: Operational use of a mesoscale model for predicting lake effect snow in upstate New York. *Preprints, 16th Conf. on Wea. Anal. and Forecasting*, Amer. Meteor, Soc., Phoenix AZ, 393-396.

Wolf, P. L., 2002: Toward better warning decision-making and verification statistics: improvements at the Wichita National Weather Service office. *Preprints, 21st Conf. on Severe Local Storms*, Amer. Meteor. Soc., San Antonio, TX., 10B.4.

Wolf, P. L., and P. Howerton, 2003: Impact of meteorological situation awareness on convective warning decision-making: A weather event simulator experiment. [Available at: http://strc.comet.ucar.edu/wes/documents/WDMexperiment.pdf]