Project Report
ATC-297

TCWF Algorithm Assessment – Memphis 2000

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16. Abstract

This report describes a formal Assessment of the Terminal Convective Weather Forecast (TCWF) algorithm, developed under the FAA Aviation Weather Research Program by MIT Lincoln Laboratory as part of the Convective Weather Product Development Team (PDT). TCWF is proposed as a Pre-Planned Product Improvement (P^3I) enhancement to the operational ITWS currently scheduled for deployment at major airports in 2002. The TCWF Assessment in Memphis, TN ran from 24 March to 30 September 2000. The performance of TCWF was excellent on the large scale, organized storm systems it was designed to predict, and the software was extremely stable during the Assessment. Small changes to the algorithm parameters were made as a result of the 2000 testing. The TCWF performance can be improved on airmass storms and on forecasting new growth and subsequent decay of large-scale storms. These are active areas of research for future ITWS P^3I builds.

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ABSTRACT

This report describes a formal Assessment of the Terminal Convective Weather Forecast (TCWF) algorithm, developed under the FAA Aviation Weather Research Program by MIT Lincoln Laboratory as part of the Convective Weather Product Development Team (PDT). TCWF is proposed as a Pre-Planned Product Improvement (P^3I) enhancement to the operational ITWS currently scheduled for deployment at major airports in 2002. The TCWF Assessment in Memphis, TN ran from 24 March to 30 September 2000. The performance of TCWF was excellent on the large scale, organized storm systems it was designed to predict, and the software was extremely stable during the Assessment. Small changes to the algorithm parameters were made as a result of the 2000 testing. The TCWF performance can be improved on airmass storms and on forecasting new growth and subsequent decay of large-scale storms. These are active areas of research for future ITWS P^3I builds.

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1. INTRODUCTION

1.1 BACKGROUND

Air traffic delay due to convective weather reached historically high levels in 1999, as passengers blamed airlines and airlines blamed the FAA for the massive inconveniences. While coordination between the FAA's System Command Center and the regional centers and terminals was intended to improve the delay situation in 2000, the summer delay due to convective weather (April through October) again reached record levels (Figure 1). Although many factors contribute to delay [1], it is clear that efficient air traffic management and planning during convective weather will ultimately require accurate convective weather forecasts. In addition to improving system capacity and reducing delay, convective forecasts can help provide safer flight routes as well. The crash of a commercial airliner at Little Rock, AK in June 1999 after a one-hour flight from Dallas/Ft. Worth illustrates the dangers and potential benefits that could be gained with frequently updated one-hour forecasts of convective storms.

The Terminal Convective Weather Forecast (TCWF) product has been developed by MIT Lincoln Laboratory as part of the FAA Aviation Weather Research Program's Convective Weather (PDT). Lincoln began the forecast development effort by consulting with air traffic personnel and commercial airline dispatchers to determine the needs of aviation users [2]. They indicated that convective weather, particularly line storms, caused the most consistent problems for managing air traffic. The "Growth and Decay Storm Tracker" developed by Wolfson, et al. [3] allows the generation of up to 1-hour forecasts of large scale, organized precipitation features with operationally useful accuracy. This patented technology represents a breakthrough in short-term forecasting capability, providing quantitative *envelope* tracking as opposed to the usual cell tracking. This tracking technology is now being utilized in National Center for Atmospheric Research (NCAR's) AutoNowcaster [4], the National Convective Weather Forecast running at the Aviation Weather Center [5] and by private sector vendors of meteorological data.

The TCWF product has been tested in Dallas-Fort Worth (DFW) since 1998, in Orlando (MCO) since 1999, and in New York (NYC) since fiscal year 2000 began (Table 1). These have been informal demonstrations, with the FAA William J. Hughes Technical Center (WJHTC) assessing utility to the users, and with MIT Lincoln Laboratory (LL) modifying the system based on user feedback and performance analyses. TCWF has undergone several revisions during this time period [6][7]. In Spring of 2000, the algorithm was ready to undergo a formal Assessment at the Memphis International Airport as a prerequisite to an FAA operational requirement. The FAA Technical Center will make a recommendation on whether TCWF is suitable for inclusion in the FAA's operational Integrated Terminal Weather System (ITWS), which has an unmet requirement for 30+ minute forecasts of convective weather. Memphis (MEM) was selected for the TCWF Assessment since it was an ITWS Prototype site that had not been exposed to the forecast product during prior demonstrations. Operations began on 24 March 2000 and continued through 30 September 2000. Operational feedback is being assessed by the FAA Technical

Center [8], and quantitative national benefits were estimated by the MCR Federal Corporation [9]. Sunderlin and Paull estimated the reasonable range for the TCWF national benefit to be very large ($443.5 million to $660.8 million, at 80 percent and 20 percent confidence levels, respectively). This report describes the technical performance of the TCWF algorithm during the formal assessment period.

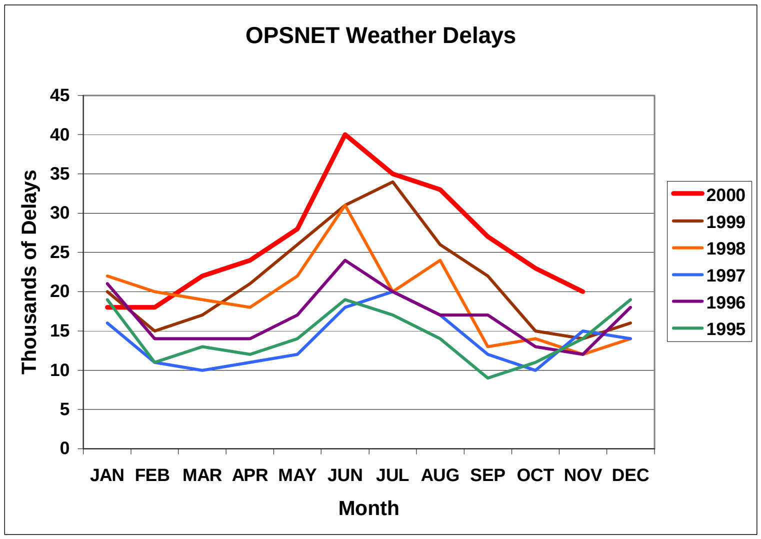

Figure 1. OPSNET Delay attributed to Weather for the years 1995 – 2000.

TABLE 1
TCWF Ongoing Demonstration

Year	Location	Prediction Time
1998	Dallas/Ft. Worth	30-60 min
1999	Dallas/Ft. Worth Orlando New York	30-60 min
2000	Dallas/Ft. Worth Orlando New York Memphis	30-60 Formal Assessment

1.2 RELATIONSHIP TO ITWS

The Terminal Convective Weather Forecast (TCWF), developed by the Aviation Weather Research Program (AWRP), has always been viewed as a Pre-Planned Product Improvement (P^3I) to the Integrated Terminal Weather System (ITWS). ITWS is a fully automated system, which is designed to improve the safety, efficiency, and capacity of terminal-area aviation operations. The ITWS will acquire data from Federal Aviation Administration (FAA) and National Weather Service (NWS) sensors, as well as from aircraft in flight in the ITWS coverage area. It will provide aviation-oriented weather products that are immediately usable by air traffic personnel in control towers, Terminal Radar Approach Control Facilities (TRACONs), Traffic Management Units (TMUs), and Center Weather Service Units (CWSUs), without requiring further meteorological interpretation.*

The initial suite of ITWS products includes characterizations of current terminal-area weather conditions, and short-term (10- and 20-min) predictions of significant weather phenomena. The ITWS products are presented to users on a graphical situation display (SD) and an alphanumeric ribbon display terminal Ribbon Display Terminal (RBDT), and are provided to data ports for use or dissemination by other systems (e.g., data link and terminal automation).

The ITWS Operational Requirements Document Operational Requirements Document (ORD, 1/95) states that pre-planned product improvement capabilities such as "a) Storm growth/decay identification" and "… e) Precipitation prediction" will be needed. The final paragraph of the ORD states (emphasis added):

> The ITWS is expected to be an evolutionary system. Attainment of post Initial Operational Capability (IOC) capabilities will be attained through a series of builds. With each successive build, new or enhanced algorithms [such as listed above] will be incorporated. Failures to implement these advanced algorithms, <u>especially those related to storm growth and decay</u>, will seriously limit improvements in capacity and margin-of-safety.

Air Traffic Requirements lists "Growth and decay forecasts of convective weather activity" as a top priority for ITWS development.

A needs assessment for convective forecasts conducted by Forman, et al. [2] revealed that users ultimately want forecasts with >90% accuracy, but would find forecasts with lower accuracy operationally useful at longer lead-times. For terminal forecasts to have planning benefit in large

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* "This research is in response to requirements and funding by the Federal Aviation Administration (FAA). The views expressed are those of the authors and do not necessarily represent the official policy or position of the FAA."

TRACONs and ARTCCs, the lead time would have to be extended from 10-20 min out to at least 1 hour. Table 2 summarizing user needs for convective weather forecasts is presented below.

TABLE 2

User Needs for Convective Weather Forecasts

Region	Users	Spatial Extent	Forecast Lead Time	Forecast Accuracy
Terminal (TRACON)	Terminal ATC Supervisors, TMCs, Pilots	50-100 nm	0.5-1 hr	70-90%
Regional (ARTCC)	Traffic Flow Management	100-200 nm	1-2 hr	50-70%
National & Oceanic	Airline Dispatchers, Command Center, Pilots	>200 nm	2-6 hr	30-50%

1.3 THE TCWF ALGORITHM

A new method for tracking storms that accounts for systematic growth and decay has been developed by Massachusetts Institute of Technology (MIT) Lincoln Laboratory under the FAA Aviation Weather Research Program's Convective Weather Product Development Team. This new technique automatically tracks the storm envelope instead of the individual cells, which has been a classic problem in radar meteorology. By effectively tracking the storm *forcing*, we account for systematic growth and subsequent decay. Quantitative scoring has shown that this approach is better at forecasting regions of heavy precipitation 30-60 min in advance than contemporary extrapolation techniques.

Byers and Braham [10] broadly categorized thunderstorms into two categories: "airmass" and "line" storms (Figure 2). More recently, Weisman and Klemp [11] defined the categories as "single cell," "multicell," and "supercell" storms. Airmass or single cell storms are small scale, seemingly random, fairly disorganized convective elements. Line storms or multicell storms are a collection of cells much like airmass cells, but they are maintained in an organized linear pattern, or "envelope." Line storms maintain this pattern because they are typically forced at a large scale by a frontal discontinuity (e.g., boundary between cold and warm air masses or between dry and moist air masses), large gravity waves, a sea breeze front, or the gust fronts from neighboring decaying cells. In the summer months, the percentage of line storms is large in the north, while airmass storms are predominant in the southeast. Line storms tend to dominate everywhere during the spring, fall and winter months. Through our assessment of user needs, we found that line storms tend to cause the most significant air traffic safety and delay threat [2]. Fortunately, they also turn out to be the most predictable types of storms.

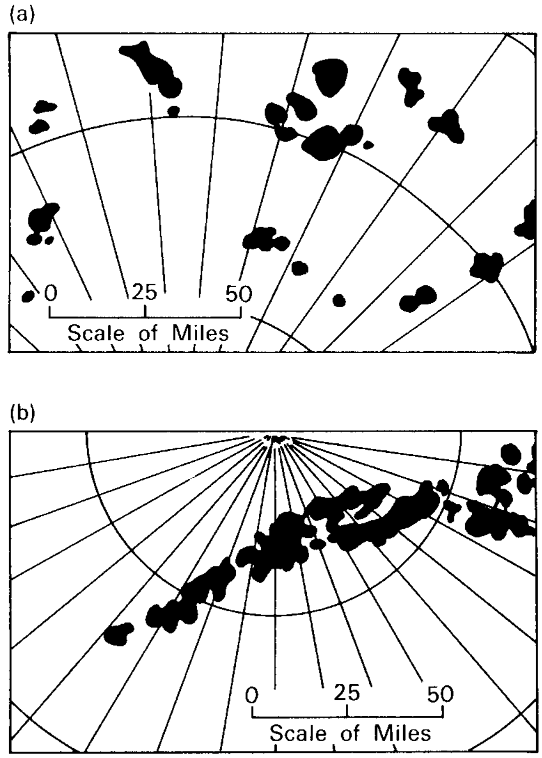


Figure 2. Comparison of airmass and line storm. (a) Radar echoes on a day of random air mass thunderstorms. (b) Radar echoes on a day of squall line thunderstorms. The radial lines and arcs indicate the azimuths and ranges from the radar site. (Redrawn from [10]).

Wilson [12] showed that strong, large scale storms in the atmosphere are inherently more persistent with time than small scale storms, and he reminded us of this in his invited speech at the 1997 Convective Weather Forecasting Workshop [13]. Since 1966, many other researchers have confirmed Wilson's findings. For example, Browning, et al., [14] noted that "individual convective rain echoes several kilometers across tended to be predictable for only 10 min or so, whereas echoes associated with mesoscale precipitation areas and rainbands 50 km across were predictable for over an hour."

Large scale organized storms are made up of clusters of single cells which are themselves short-lived. As these multicell storms propagate, new storms grow (often along a preferred flank), and old storms decay. The net storm motion is a result of this discrete propagation, and is often very different from the individual cell motion [15]. Wilson [12] found that cells tended to move with the mean wind between 10Kft and 20Kft, but that "large-scale features move more slowly and to the right of the small-scale features."

Determining the envelope motion separate from the storm cell motion is a long-standing problem in weather radar research [16]. Forecasts of future storm locations are typically made by extrapolating the motion of individual cells, using either a cross-correlation or centroid tracking technique. For very short-term predictions, this cell motion is accurate, but for longer-term predictions, the envelope must be tracked.

To determine the motion of the long-lived storm elements, the large-scale signal must be extracted and tracked. The separation of the large-scale component from the full scale can be accomplished by filtering techniques. Boundary layer forcing for convection tends to organize storms in regions that are often 3-4 or more times longer than they are wide. To match this geometry, our approach uses an elliptical filter to extract the large-scale signal. A large square filter would over-filter in the cross-front direction, but the elliptical filter allows us to extract these long narrow large-scale regions with a high degree of long-front filtering.

To illustrate the effect of elliptical filtering, we selected a line storm case on 1 June 1996 in Dallas, where the envelope motion and cell motion were quite different. The elliptical filter is applied to the Vertically Integrated Liquid water (VIL) field, or any other weather radar data to be tracked. Figure 3 shows the "full-scale" image (VIL), the large-scale image (derived with a 15x61 km elliptical filter), and the small-scale image (derived by subtracting the result of a 15x15-km filter from the unfiltered image, thus selecting all scales less than 15x15 km). Within the large and small-scale images, the storm motion vectors resulting from correlation tracking are shown. The large-scale signal is moving southeast at 34 knots, while the small-scale signal is moving northeast at 21 knots

The large-scale propagates to the southeast by virtue of new cells growing preferentially on the southeast side of the line and old cells decaying as they propagate to the northeast. We have dubbed this new elliptical filter/tracker the "Growth and Decay Storm Tracker" because it can account for this type of systematic growth and decay [3].

Filter optimization tests were conducted on 13 line storm cases from Dallas, TX; Orlando, FL; Boston, MA; and Memphis, TN [17]. Determining the "best" filter overall requires compromise, since each case day has a different optimal filter. The results showed that a filter with a size of 13x69 km and an aspect ratio of 5:1 produced the highest scores, and best approximated the large-scale features of the organized storms tested.

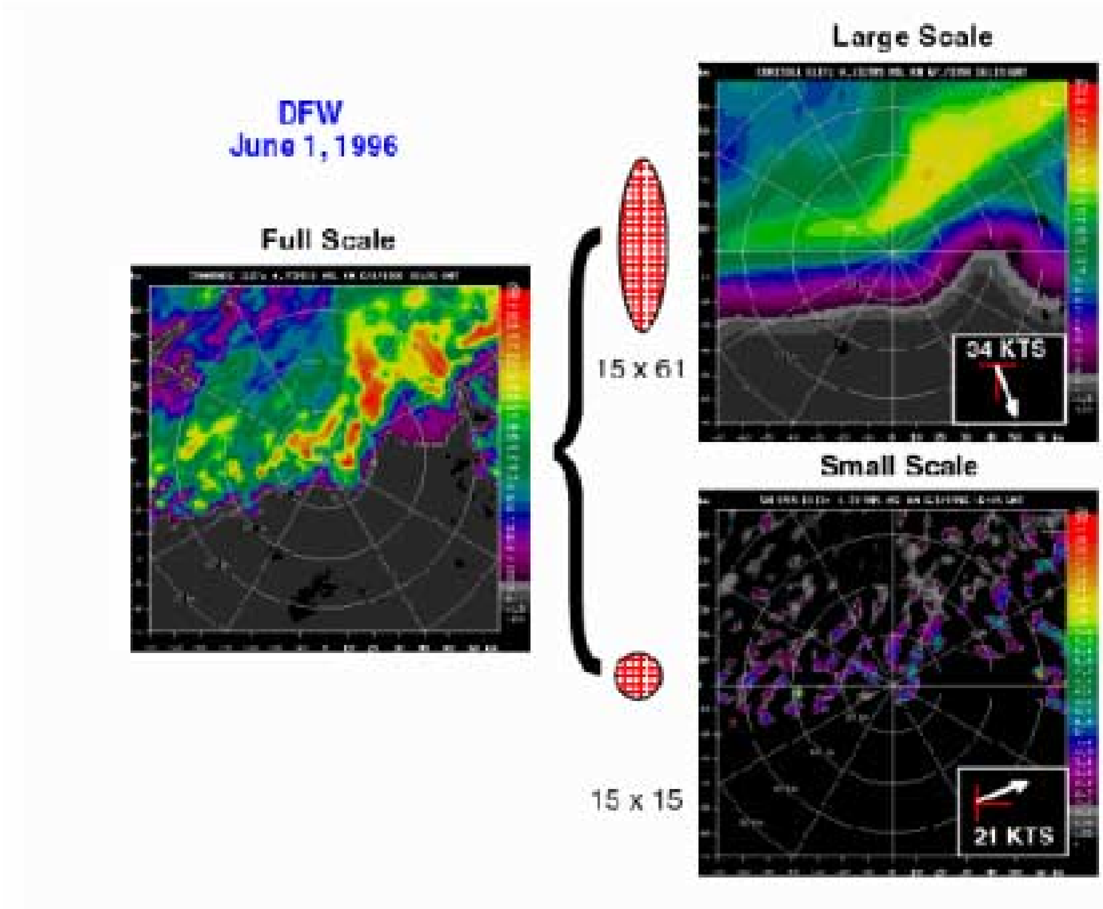


Figure 3. Example of scale separation. (Left) The result of filtering the full scale image to produce large scale and small scale images. (Right) The motion of the large scale and small scale components, found with a correlation tracker, are indicated.

1.4 2000 ASSESSMENT

The goal of the TCWF formal assessment in Summer 2000 was to determine if the 1-hour forecast algorithm was acceptable and mature enough for ultimate inclusion in the operational ITWS. The following chapter of this report describes the modifications that were made to the TCWF algorithm prior to deployment in Memphis. Details of our demonstration and the performance of the TCWF algorithm on the storms encountered in Memphis from 24 March through 30 September 2000 are given in Chapter 3. During this same time period, demonstrations were also conducted in Dallas and Orlando and descriptions can be found in Chapter 4. We addressed problems encountered at all sites during the summer 2000 demonstrations in Chapter 5.

2. TCWF ALGORITHM FOR 2000

2.1 ALGORITHM BACKGROUND

The initial TCWF algorithm was designed to provide real-time probability forecasts of $\geq$level 3 weather out to 1 hour. The product uses a two-level probability map showing regions of moderate and high probabilities of $\geq$level 3 weather, and loops from the current time to 60-min in the future in 10-min increments. Unique features of the TCWF display include animation of the real-time forecast, window manipulation, real-time forecast accuracy scoring, and forecast updates every 5-6 minutes (update time of the NEXRAD radar). Data analysis and user feedback from the DFW, MCO and NYC demonstrations revealed areas for algorithm improvement, discussed in detail in section 2.3. The algorithm used for the Memphis Assessment included these changes as well as a new display very similar to the ITWS Situation Display. Shortly after the start of the Memphis Assessment (24 March 2000), Dallas, Orlando and New York were updated with the Assessment version of the software. Table 3 shows the dates of the algorithm upgrades.

TABLE 3
TCWF 2000 Upgrades

Date	Location
March 24, 2000	Memphis
April 26, 2000	Orlando
April 29, 2000	Dallas/Ft. Worth
May 8, 2000	New York

2.2 ALGORITHM METHODOLOGY

The TCWF prototype demonstrations use the Next Generation Weather Radar (NEXRAD) wide-band radar data as their primary source. Two-dimensional Cartesian files of 1-km resolution Vertically Integrated Liquid water (VIL) are created from the NEXRAD VIL algorithm. VIL images are then remapped into “interest images” using an equation developed by Troxel and Engholm [18]. The interest images depict the standard Video Integrator Processor (VIP) levels, making it possible for TCWF eventually to use other radars in the algorithm [(i.e., Terminal Doppler Weather Radar (TDWR) or Airport Surveillance Radar–9 (ASR-9)].

The elliptical filtering to extract the envelope motion used to make the forecasts (described in 1.3) was performed using a variation of the Fast-Fourier Transform (FFT) methodology suggested by Lakshmanan [19]. This decreased the processing time by a factor of ~30 relative to our original functional template correlation filtering on 1-km resolution images. The filtered storms are tracked using the ITWS Cross-Correlation Tracker. A complete list of all the Tracker parameters used by the algorithm can be found in Appendix A.

Our research has determined that processing at 1-km resolution is not only essential for creating accurate forecasts when slow-moving airmass or small-scale storms dominate, but also improves forecast accuracy on large-scale organized storms. The 1-km grid of vectors is used to create two forecast products: the TRACON forecast, at a 1-km resolution (440km x 440km) grid and the 200nm forecast, at a 2-km resolution (640km x 640km) grid. These forecasts are then truthed against the actual weather to verify detections, misses, and false alarms. A User Critical Success Index (CSI) score representing the forecast accuracy is calculated and reported for both the 30- and 60-minute forecasts and displayed for both the TRACON and the 200nm products. Details on the scoring techniques can be found in Section 2.3.4 and in Appendix B.

2.3 ALGORITHM REFINEMENTS PRIOR TO MEM ASSESSMENT

The TCWF algorithm that ran during the MEM Assessment (as well as at the other sites since the upgrades) included several refinements addressing problems that were discovered during the previous site demonstrations in DFW, MCO and NYC. The MCO demonstration was very instrumental in diagnosing algorithm and display issues, mostly related to the airmass weather events that dominate the region. The product development team continues to research ways in which these issues can be resolved. The changes that were made prior to the MEM Assessment are described in the following sections.

2.3.1 Re-code in C++

In an effort to make the code more generic and transferable (anticipating the specification for P^3I ITWS), the algorithm was recoded from its original Lisp language into C++. Testing was performed on several baseline cases for verification. Future enhancements such as adding feature detectors developed in C++ into the algorithm will also be easily accomplished.

2.3.2 4-km to 1-km Resolution

The new 1-km data resolution was implemented, requiring the FFT method of filtering for computational speed. Analysis showed that TCWF would often forecast excessive motion for quasi-stationary storms. Studies revealed that the underlying 4km-grid resolution was too coarse, requiring the Growth and Decay Storm Tracker to choose either 0 or 1 pixel motion over the 12-minute correlation interval for the slow-moving storms. The choice of 1 pixel (4-km in 12 minutes) led to erroneous rapid motion. It was clear that the 1-km resolution vastly improved the forecast quality from the several test cases that were examined. Figure 4 illustrates the differences in forecast maps and vectors at the 4-km and 1-km resolutions. The change from 4-km to 1-km resolution had implications for the generation of TCWF forecast accuracy scores, described in section 2.3.4.

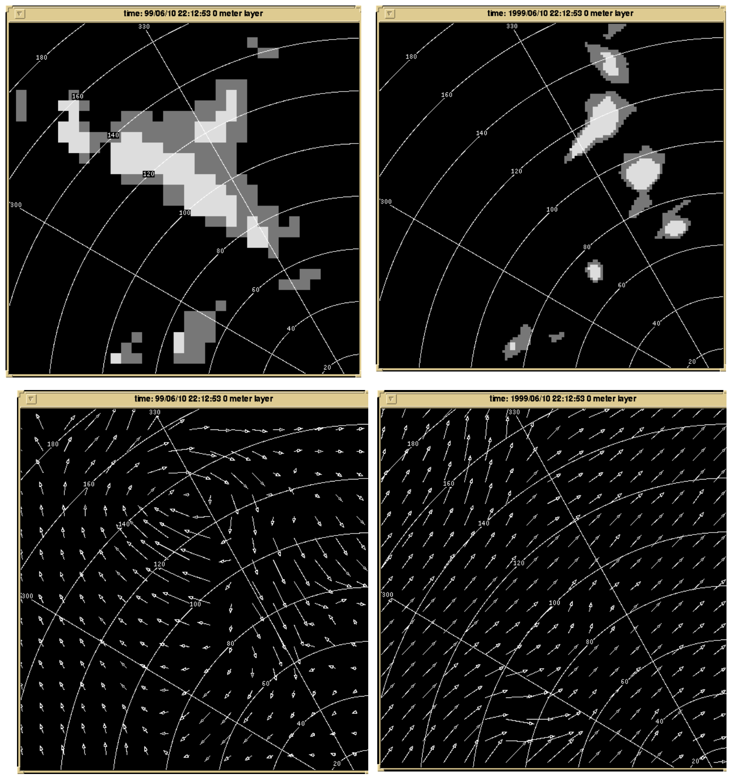


Figure 4. Illustrates the improvements made in MCO on 10 June 1999 to TCWF by changing from 4-km resolution to 1-km resolution. The left-hand side is the 4-km resolution while the 1-km resolution is depicted on the right. (a) Shows the 60-min forecast, light gray showing high probability of level 3 weather, and moderate probability denoted in the darker gray. (b) These images show the Tracker vector motions. The 1-km resolution avoids the bizarre vector motions shown in the 4-km resolution.

2.3.3 Cosmetic Smoothing

Cosmetic improvements were also made to the forecasts prior to the MEM Assessment. The TCWF forecast map shows color-coded regions of moderate and high probability of ≥3 precipitation. By using the ITWS tracker to forecast 1-km resolution features out to 1-hr, an unrealistic graininess resulted and needed to be addressed. A smoothing technique using a binary dilation plus a mean filtering step (Figure 5) is performed on the images. This process slightly increases user scores.

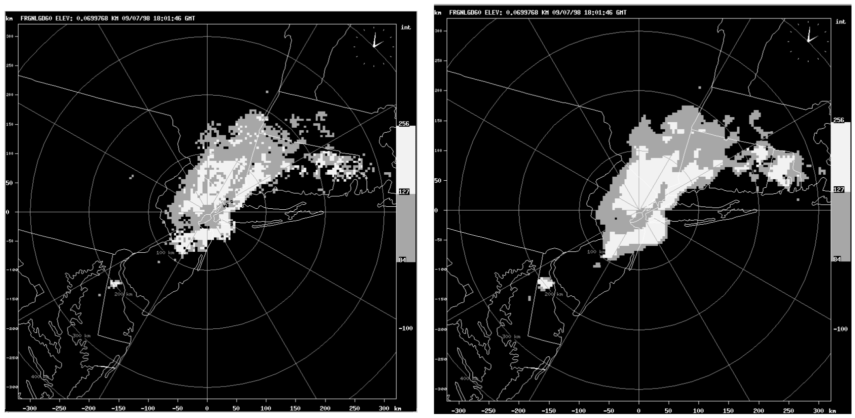


Figure 5. Effects of using smoothing operations on the forecast image. The image on the left is the forecast prior to any smoothing operations. The forecast on the right shows the cosmetic improvement after smoothing.

2.3.4 1 km Scoring Optimization

The increase in data resolution from 4-km to 1-km required that we modify our performance scoring procedure accordingly. Appendix B describes our "binary", "box" and "user" scoring techniques. The change from 4-km to 1-km resolution does not affect the binary scores, but both the box and user scores require the selection of a scoring box radius and the number of pixels to count as a "hit." The goal of the optimization was to find values for these two parameters that would yield 1-km scores that were approximately equal the corresponding 4-km scores, which had previously been developed to match users' impressions of forecast quality[*]. The scoring box radius is the "radius" of the scoring box that surrounds a pixel. For example, a box radius of 7-km yields a square box with each side measuring 15-km, at the center of which is the pixel to be scored. Also, a minimum number of pixels are required within the scoring box for the forecast pixel to count as a hit.

Forecast scores will increase with box size because as a larger area is searched, more valid forecast pixels are possible. However, an increase in the number of pixels to count for a hit will decrease the forecast score because it requires more valid forecast pixels within each scoring box.

The two scoring variables were optimized using three test cases: 4 June 1998 and 1 June 1996 from Dallas/Fort Worth and May 5, 1999 from Memphis. All three of these test cases were line storm weather events.

1. The 1-km resolution box size radius was tested at varying sizes, from 7-km to 10-km in 1-km increments for the optimization study. The scoring box sizes ranged from 15x15 km to 21x21 km.
2. The number of pixels that would count for a hit was varied from 1 to 16.

[*] Users have consistently stated that the 1-hr forecast should be accurate within 5nm (~10 km).

3. The 4-km resolution data was scored using a box radius of 2, giving a 5 x 5 pixel (4-km pixels) scoring box (20x20-km). The 4-km resolution requires only one valid 4-km pixel to count for a hit. The upper limit of 16 in the 1-km case corresponds to a single 4-km x 4-km box , the equivalent of the 4-km resolution case for 1-km.

Initial results yielded a box size of 9 (19x19-km) with 8 pixels required to count as a hit to best match the 4-km scores. A bug in the scoring software was discovered during the Assessment, which changed the results of the optimization. Essentially, a region of the forecasts was not being scored so depending on the location of the weather in the cases tested, scoring results varied. The optimal setting (post bug fix) proved to be a (19x19-km) kernel, requiring 16 pixels for a match. (See section 5.2.1 for further details of the scoring bug.)

2.3.5 Tracon vs. 200nm Scores

Previously, the TCWF algorithm only reported one score based on the entire 200nm-range grid. Users noted their preference for two forecast scores, one for the TRACON range and another for 200nm range. The change was made prior to the Memphis Assessment to display two scoring ranges. Figure 6 illustrates the forecast accuracy dialog boxes for both viewing ranges.

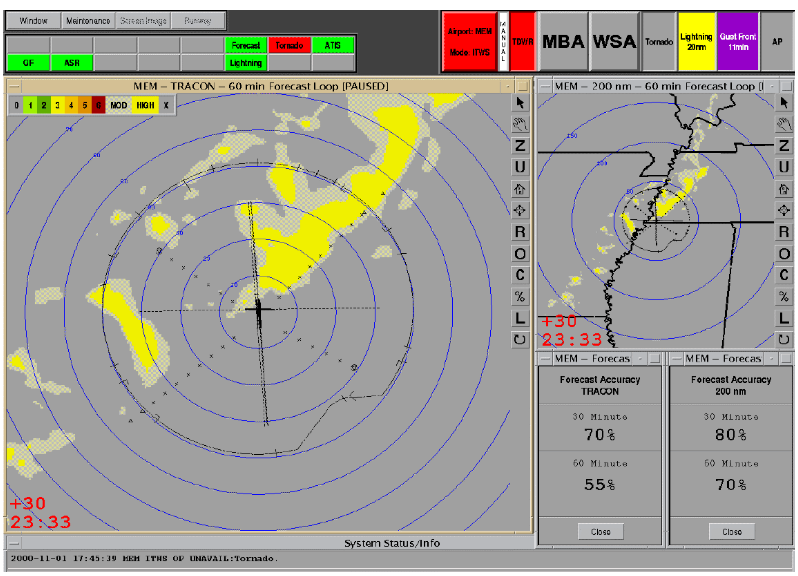


Figure 6. An example illustrating Forecast Accuracy scores on the TCWF display. Forecast Accuracy dialog boxes are shown for both the TRACON and 200nm ranges, corresponding to the TRACON and 200nm forecast windows shown in the TCWF Display.

2.3.6 TCWF Display

The decision was made to change from the web-based display to a display based on the ITWS Situation Display (SD) for the Memphis Assessment. There are several advantages to doing this. The primary reason for this change is to provide the TCWF users with a display concept close to what they would expect to see in an operational ITWS. Since the purpose of the MEM Assessment was to determine if TCWF would be suitable for inclusion in ITWS, we chose to display TCWF on an ITWS-like display. All functions of the TCWF display (e.g., pan, zoom, overlays, etc.) act just as they do on ITWS. This made training much simpler since the users were already familiar with the ITWS display, and could focus their attention on the new product, rather than a completely new interface. Since the inclusion of TCWF in ITWS was not definite at the start of the Memphis Assessment, the Air Traffic Requirements branch requested that TCWF be displayed on a separate monitor next to the prototype ITWS monitor. Air Traffic Control (ATC) users received this additional TCWF-only display while airline users received a replacement integrated TCWF/ITWS display that showed both ITWS and TCWF on the same wide monitor. A web-based display continued to be available for those users without dedicated displays. Figures 7, 8, and 9 illustrate the three displays used in the TCWF Assessment.

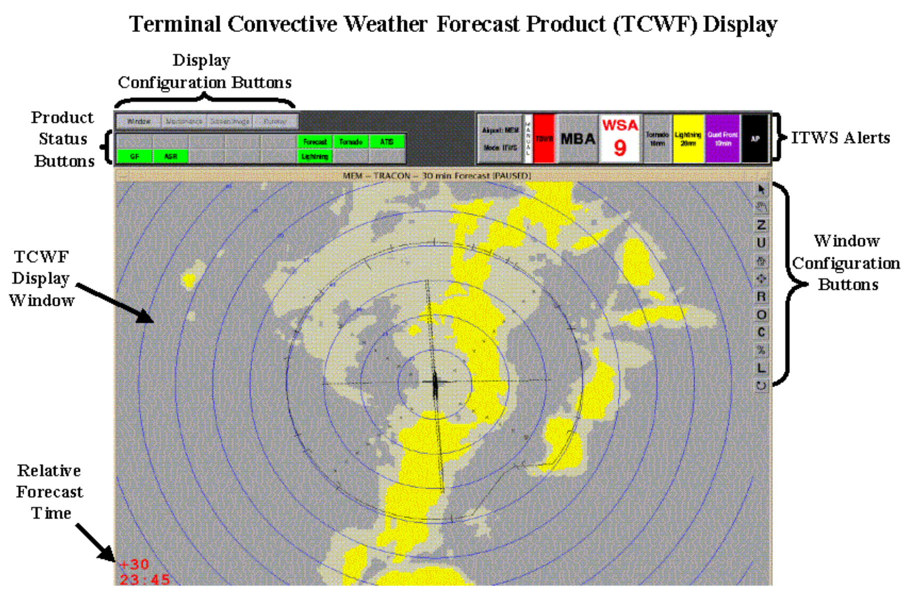


Figure 7. An example of the TCWF-Only SD. The ATC community views the TCWF product on TCWF-only SD. This is a display very similar to ITWS in that it has many of the same features and functions, but the TCWF product is the only product displayed. The TCWF-only display allows all of the ITWS safety status and alert information to be passed through, yet only displays the TCWF product in the graphics windows.

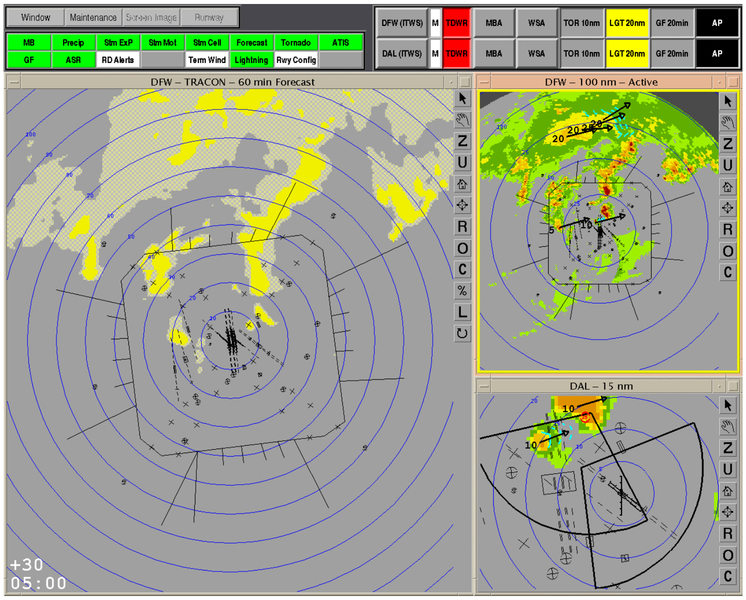


Figure 8. Example of the Integrated TCWF/ITWS display. Airline users, such as Federal Express, Northwest, Delta, American, United, and Continental all view the TCWF product via an Integrated TCWF/ITWS display. These users see all of the ITWS products as well as the TCWF products on one display. A wide monitor was selected to accommodate the additional information.

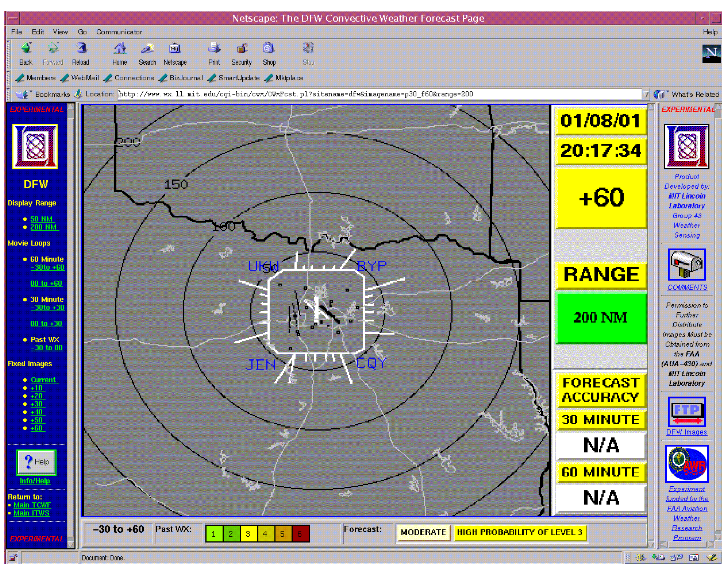


Figure 9. Example of the TCWF webpage. The airlines without dedicated lines to the ITWS prototypes, and other authorized users access the TCWF product information via a webpage. Loop control and two range settings are available.

3. MEMPHIS ASSESSMENT

In this chapter we describe the preparations for the Memphis Assessment and present the detailed results of the TCWF algorithm performance evaluation. The TCWF algorithm also ran in Orlando and Dallas during the summer of 2000. The results of those demonstrations are presented in Chapter 4.

3.1 DEMONSTRATION ARCHITECTURE

The Memphis Assessment was hosted at the Memphis ITWS Prototype site, and reached users in the Memphis TRACON, at the TMU and CWSU in the Memphis ARTCC, and at several airlines through dedicated lines and/or the Collaborative Decision Making (CDM)-Net or Internet webpages. A diagram of the demonstration is shown in Figure 10.

Hardware specialists faced several challenges regarding phone line and hardware installations in the facilities. The phone line to the ARTCC was upgraded from 56K to 128K necessitating higher speed modems. Space in the facilities was limited, making it difficult to fit dual monitors for ITWS and TCWF in the specified areas. In addition, some rewiring was needed in order to accommodate the new machines, especially in the TRACON. Table 4 shows the various displays deployed in Memphis as part of the Assessment. The flat screen monitor for the Memphis TRACON was the only solution possible for the TCWF display because their space constraints.

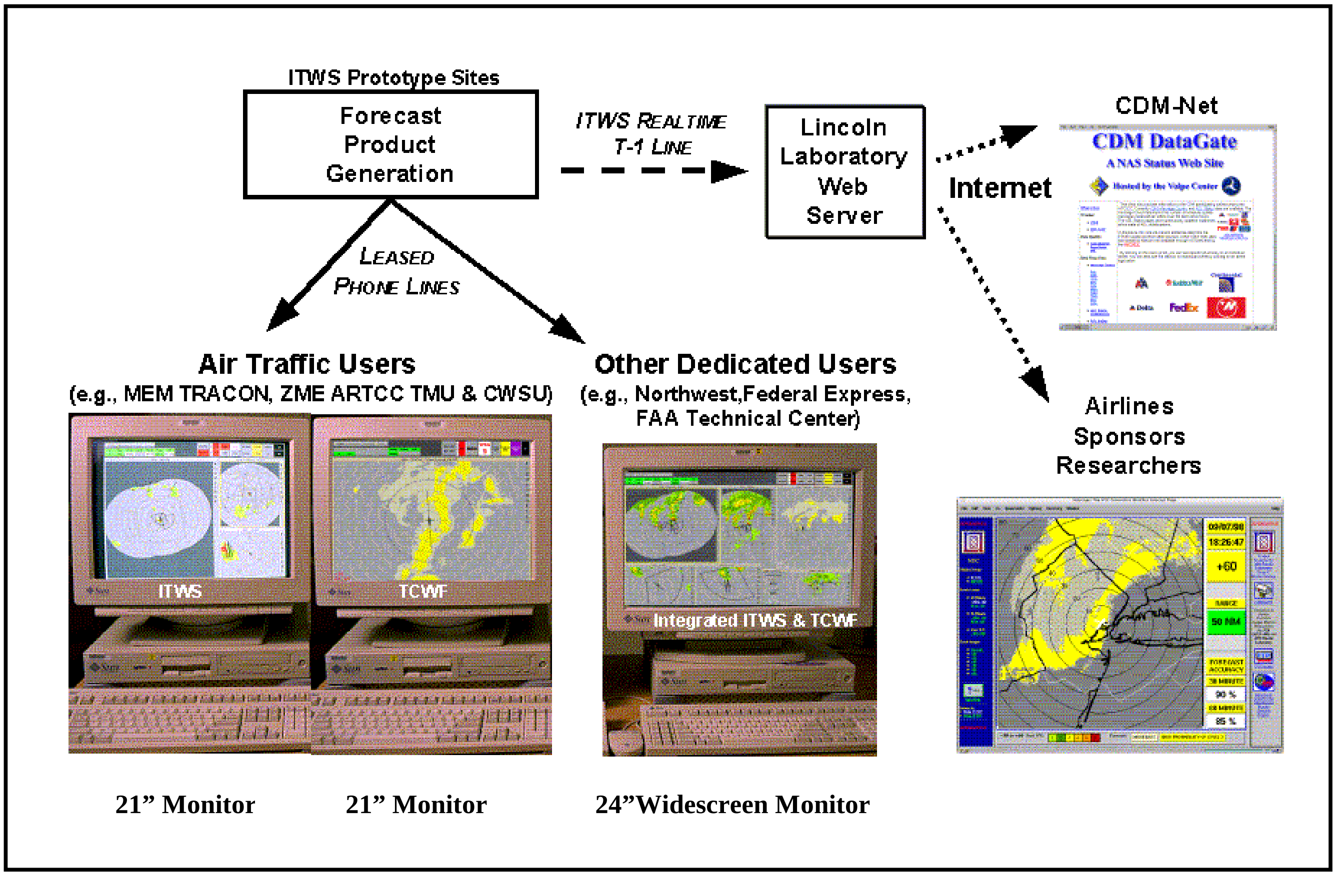


Figure 10. Memphis Convective Weather Forecast Demo.

TABLE 4

List of displays deployed for the MEM Assessment

Display Type	Hardware	Location
TCWF	21" flat screen monitor	Memphis TRACON
TCWF	21" monitor	Memphis ARTCC – TMU
TCWF	21" monitor	Memphis ARTCC – CWSU
Integrated	24" widescreen	Federal-Express Global Ops Center
Integrated	24" widescreen	Northwest Dispatch (Minneapolis)
Integrated	24" widescreen	Northwest – Meteorology/Memphis dispatch (Minneapolis)
Integrated	21" monitor	Memphis Site

3.2 USER TRAINING

Training was performed at all of the MEM facilities on the dates listed in Table 5. Training sessions included a viewgraph presentation as well as a hands-on demonstration at the display, totaling 30-45 minutes. Topics presented during training included:

- TCWF demonstration locations
- Airmass and line storm characteristics
- Differences between cell motion and envelope motion
- Algorithm background and architecture
- Examples of the forecasts and performances from 1999 demos
- Product display
- Animation choices, range selection, real-time scoring
- Webpage and CDM-Net availability

Users were also given detailed reference guides about the TCWF display. Figure 11 gives an example of the TCWF-Only guides that were given to the ATC users. Similar reference guides were given to the airlines highlighting the Integrated SD setup. Phone contacts were also included so the appropriate site personnel could be contacted for trouble-shooting efforts. During training and beyond, suggestions made by the users were noted and will be addressed during the next ITWS users group meeting.

TABLE 5
Dates of User Training in Memphis

Date	Users Trained
March 7, 2000	TRACON Supervisors
March 30, 2000	CWSU Meteorologists
April 3, 2000	Traffic Managers
May 24, 2000	Federal Express ATC Coordinators

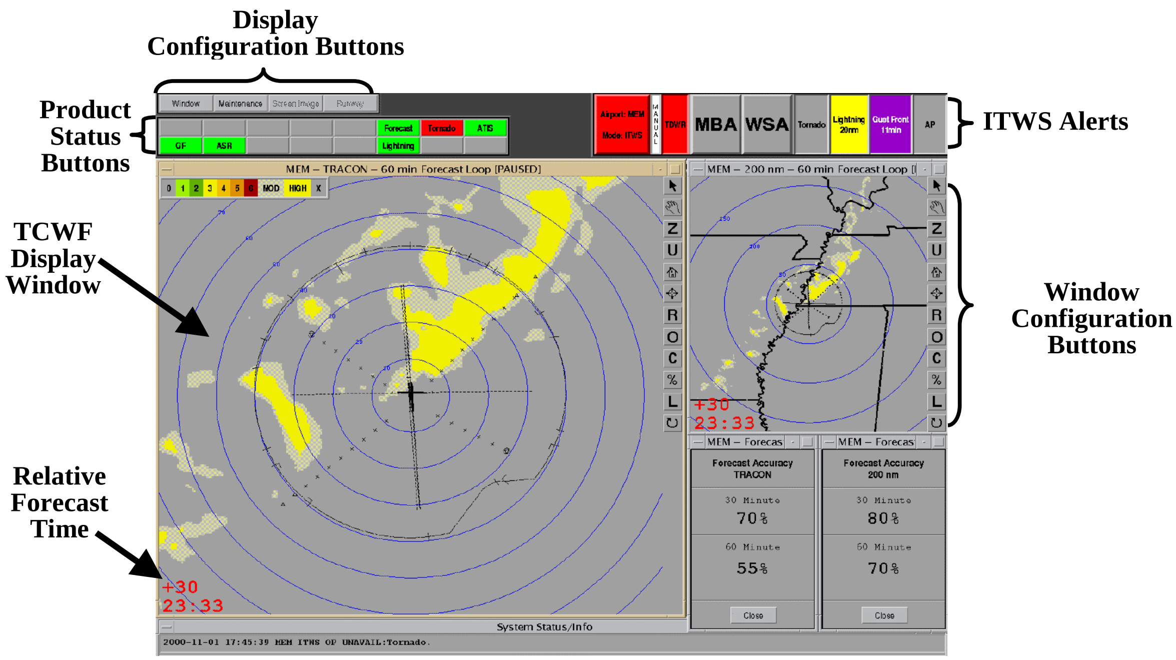
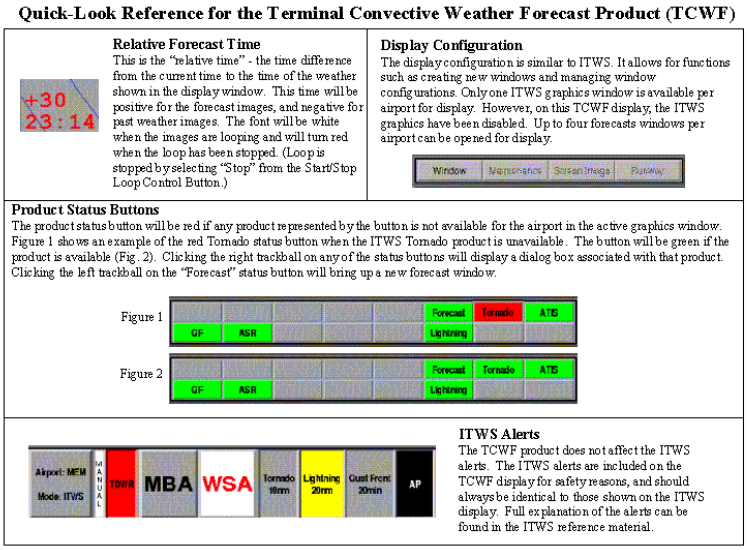


Figure 11. Example of the "Quick Look Reference" cards. These were given to the ATC for explanation of various features of the display. (Continued on following page.)



Quick-Look Reference for the Terminal Convective Weather Forecast Product (TCWF)

Relative Forecast Time
This is the "relative time" - the time difference from the current time to the time of the weather shown in the display window. This time will be positive for the forecast images, and negative for past weather images. The font will be white when the images are looping and will turn red when the loop has been stopped. (Loop is stopped by selecting "Stop" from the Start/Stop Loop Control Button.)

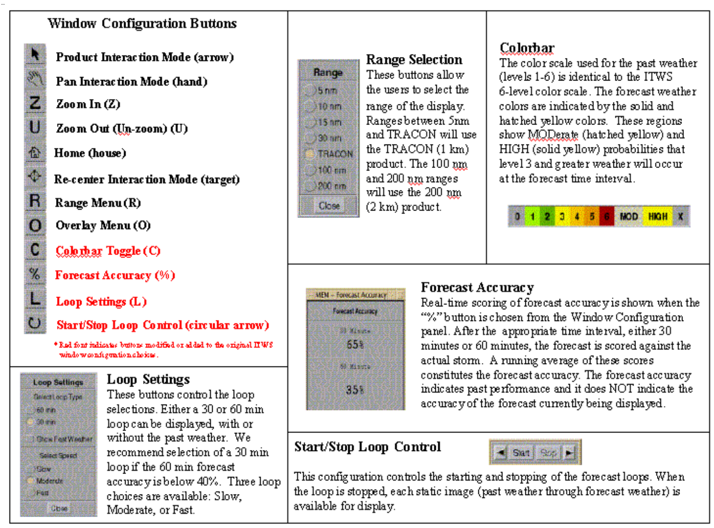
Display Configuration
The display configuration is similar to ITWS. It allows for functions such as creating new windows and managing window configurations. Only one ITWS graphics window is available per airport for display. However, on this TCWF display, the ITWS graphics have been disabled. Up to four forecasts windows per airport can be opened for display.

Product Status Buttons
The product status button will be red if any product represented by the button is not available for the airport in the active graphics window. Figure 1 shows an example of the red Tornado status button when the ITWS Tornado product is unavailable. The button will be green if the product is available (Fig. 2). Clicking the right trackball on any of the status buttons will display a dialog box associated with that product. Clicking the left trackball on the "Forecast" status button will bring up a new forecast window.

Figure 1

Figure 2

ITWS Alerts
The TCWF product does not affect the ITWS alerts. The ITWS alerts are included on the TCWF display for safety reasons, and should always be identical to those shown on the ITWS display. Full explanation of the alerts can be found in the ITWS reference material.



Window Configuration Buttons

- Product Interaction Mode (arrow)
- Pan Interaction Mode (hand)
- Zoom In (Z)
- Zoom Out (Un-zoom) (U)
- Home (house)
- Re-center Interaction Mode (target)
- Range Menu (R)
- Overlay Menu (O)
- Colorbar Toggle (C)
- Forecast Accuracy (%)
- Loop Settings (L)
- Start/Stop Loop Control (circular arrow)

* Red font indicates buttons modified or added to the original ITWS window configuration choices.

Range Selection
These buttons allow the users to select the range of the display. Ranges between 5nm and TRACON will use the TRACON (1 km) product. The 100 nm and 200 nm ranges will use the 200 nm (2 km) product.

Colorbar
The color scale used for the past weather (levels 1-6) is identical to the ITWS 6-level color scale. The forecast weather colors are indicated by the solid and hatched yellow colors. These regions show MODerate (hatched yellow) and HIGH (solid yellow) probabilities that level 3 and greater weather will occur at the forecast time interval.

Forecast Accuracy
Real-time scoring of forecast accuracy is shown when the "%" button is chosen from the Window Configuration panel. After the appropriate time interval, either 30 minutes or 60 minutes, the forecast is scored against the actual storm. A running average of these scores constitutes the forecast accuracy. The forecast accuracy indicates past performance and it does NOT indicate the accuracy of the forecast currently being displayed.

Loop Settings
These buttons control the loop selections. Either a 30 or 60 min loop can be displayed, with or without the past weather. We recommend selection of a 30 min loop if the 60 min forecast accuracy is below 40%. Three loop choices are available: Slow, Moderate, or Fast.

Start/Stop Loop Control
This configuration controls the starting and stopping of the forecast loops. When the loop is stopped, each static image (past weather through forecast weather) is available for display.

Figure 11. (Continued from previous page.) Example of the "Quick Look Reference" cards. These were given to the ATC for explanation of various features of the display.

3.3 MEMPHIS WEATHER EVENTS

The TCWF Assessment formally began on 24 March 2000 in Memphis. The algorithm was tested the very next day when a cold front brought convection to the area -- the first of many weather events to impact Memphis. The Assessment period contained 58 days of operations during the spring and summer months, coming to a close on 30 September 2000. Numerous weather episodes allowed for a variety of data collection, highlighting many algorithm strengths as well as some limitations. There were several days in which TCWF had exceptional performance and user benefits were high. There were also a couple of days on which algorithm problems unfolded and were promptly addressed by the development team (Chapter 5).

Figure 12 highlights the days with weather events in Memphis for the 2000 Assessment. Appendix C contains a complete list of these days (Table C-1), with a synopsis of the weather and a summary of the TCWF performance for each day. The Memphis site staff typically phoned the users after a weather event and discussed the benefits, as well as any problems, that may have been encountered using TCWF. Table C-1 also lists the benefits and problems noted with the TCWF algorithm.

Performance statistics were calculated for all the operational Memphis days. Table C-2 gives the daily averages of the various forecast scores (binary, box, and user) as well as the total duration of the event, number of truth pixels, and forecast bias numbers. (Refer to Appendix B for a detailed description of scoring methods.) When looking at the table, it is important to note that days with low pixel counts do not have the same statistical significance as days with higher pixel counts. Also note that these results were gathered in real-time and that any bug fixes or algorithm enhancements are not represented in the days prior to the release of the fix. The overall 30 and 60-minute user scores from these events are presented as a bar graph in Figure 13.

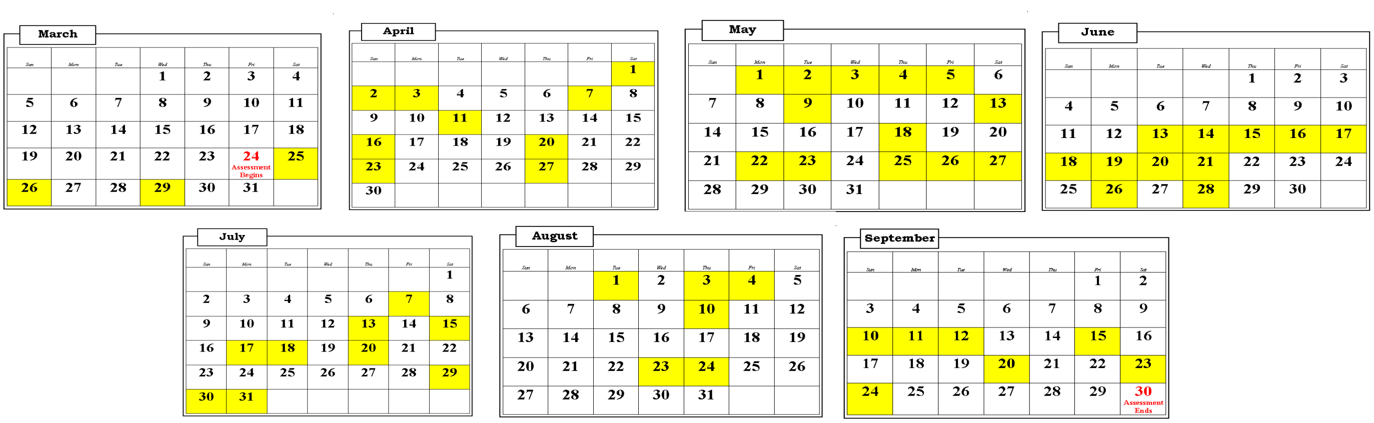


Figure 12. Days highlighted reflect operational days during the 2000 Memphis Formal Assessment.

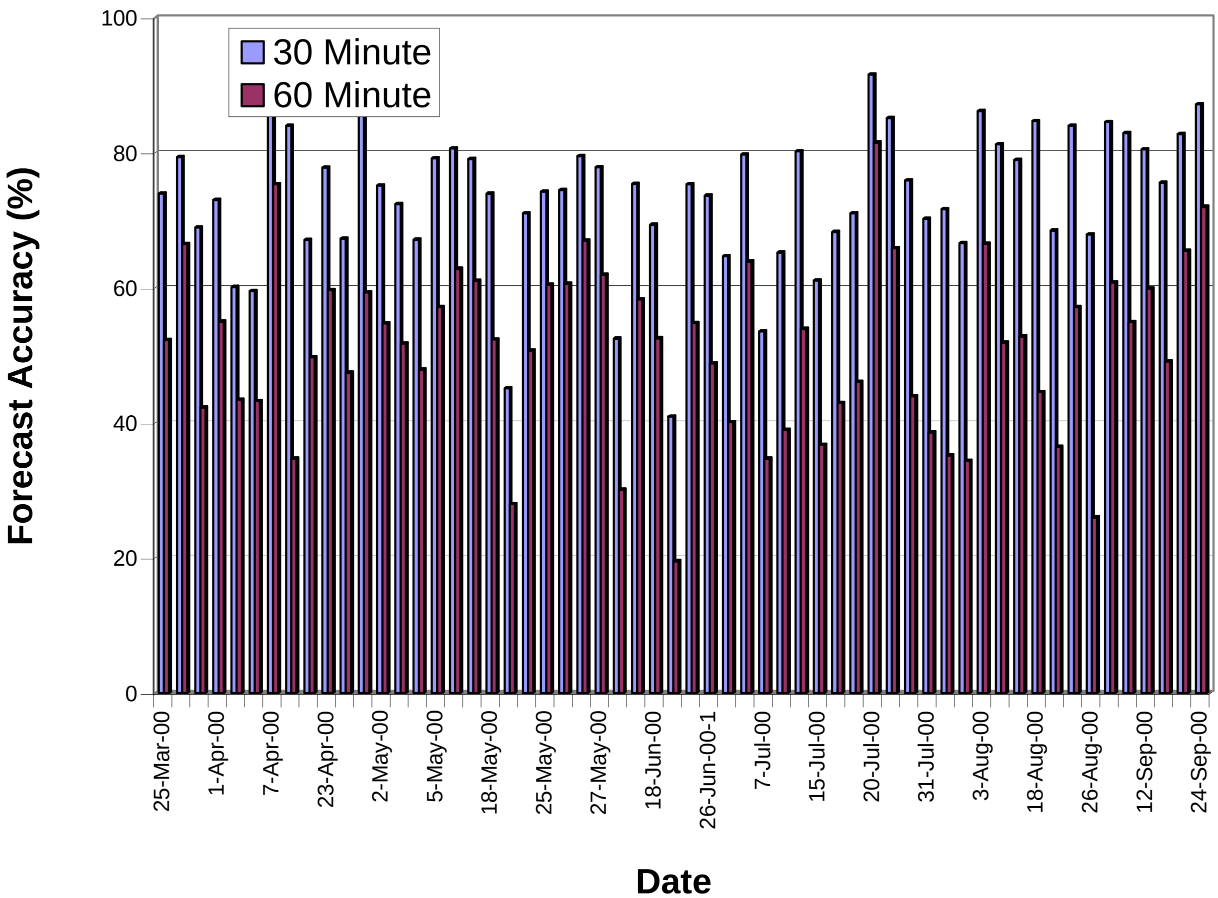


Figure 13. MEM performance scores for the 2000 cases. Blue bars indicate the average 30 minute forecast user scores while the red represents the average 60 minute user scores.

3.4 HIGH PRIORITY CASES

Although there were several weather impacts throughout the MEM Assessment, it seems appropriate to highlight a few of the most important ones. The greatest benefits of the TCWF product were realized on the following days:

7 April 2000

9 May 2000

20 July 2000

24 September 2000

Synopses of these weather events are given in Table C-1 while more detailed operational benefits are discussed below. Note that user-stated benefits are most often combined ITWS/TCWF benefits, though occasionally TCWF-only benefits are described. Figures illustrating the performance of the TCWF algorithm on each of these cases are presented after the operational benefits discussions. All scores presented are user scores.

3.4.1 Operational Significance

7 April 2000 (See figures 14-17)

Site personnel reported that TCWF predicted the arrival of the storms at the airport to within 5 minutes on the 30-minute forecasts and within 10 minutes on the 60-minute forecasts. This was an important event as a bow echo developed and threatened the airport.

Northwest Airlines (NWA) used TCWF/ITWS for weather briefings and to determine gaps in the weather, in case their planes were caught on the east side of the line.

The TMU used the forecast product to determine the timing of the airport impact and plan the arrival push accordingly.

9 May 2000 (See figures 18-21)

This squall line affected the NWA evening push. NWA users stated that they were able to proactively make decisions that allowed the airspace to be utilized as fully as possible. They also used the products extensively during the pre-flight and en-route briefings. NWA estimated that there were 6 saved diversions based on the use of the TCWF/ITWS products.

The TMUs used the products to determine which gates would open first and thus plan to route traffic towards those gates. The aircraft were therefore allowed to enter the airspace sooner, resulting in reduced hold times. In fact, they used the products to determine when and where to hold aircraft.

The TRACON users felt the products helped to minimize the hold times, regulate the flow with the Center, and land more aircraft prior to runway closure.

20 July 2000 (See figures 22-25)

A conversation with the Northwest Airlines (NWA) chief dispatcher on duty revealed that they relied heavily on TCWF to plan airport impact timing. TCWF and their meteorologists disagreed a little on the forecast timing, and the actual weather actually split the difference between the two forecasts. Because of the forecast, they planned to have all departures out by the time the line arrived. There were no diversions, delays, or holds during this event.

24 September 2000 (See figures 26-29)

Although the mission was long, the air traffic impacts were primarily limited to the morning NWA push. TCWF did a great job, with the main system benefits of shared situational awareness, providing deviation headings, and reconfiguring the arrival and departure gates. The TCWF product provided an added benefit by showing that the airport would escape the strongest convection.

3.4.2 Performance Evaluation

For each of the days discussed above, a series of figures is presented on the following pages to illustrate the performance of the TCWF algorithm. For each case, the first page shows two figures: on top, an image of the ITWS SD to convey the overall storm situation, and on the bottom, a timeseries plot of the 30- and 60-min performance scores over the duration of the case. The second page shows two images each for the 30-min (top) and 60-min (bottom) forecasts: the images on the left are the 30- and 60-min forecasts with the two levels of probability (grey – moderate probability and yellow – high probability of ≥ level 3 precipitation), and the images on the right are forecast scoring plots indicating the performance as hit (green), miss (blue) or false alarm (red). (See Appendix B for a full explanation.)

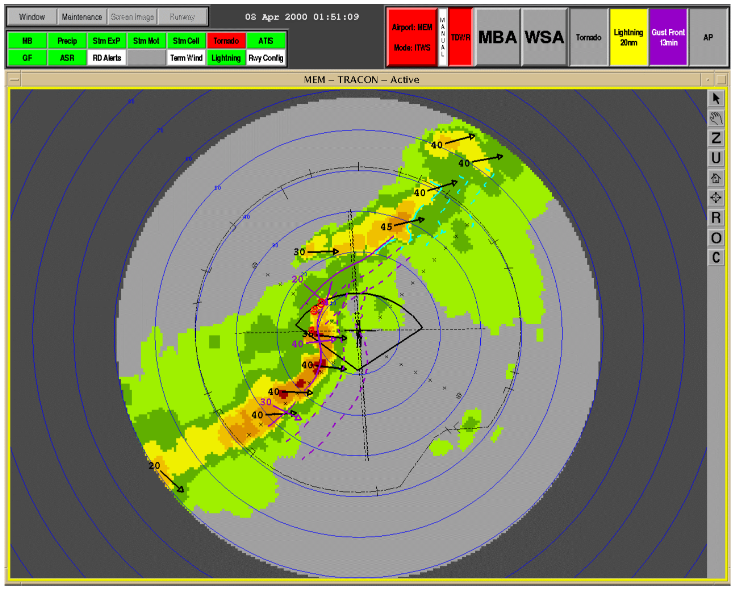


Figure 14. Image of the ITWS SD illustrating the weather impact on 7 April 2000.

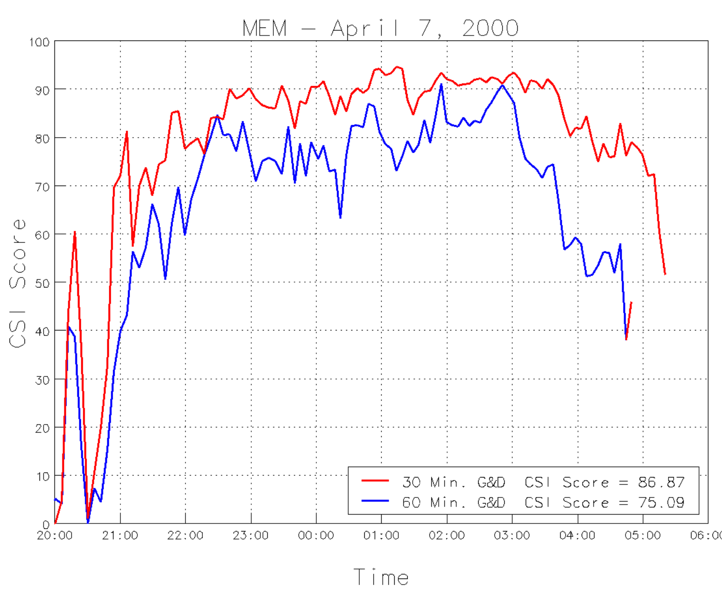


Figure 15. Timeseries plot for 7 April 2000. The red curve indicates the 30-minute forecast accuracy scores, while the blue curve indicates the 60-minute scores.

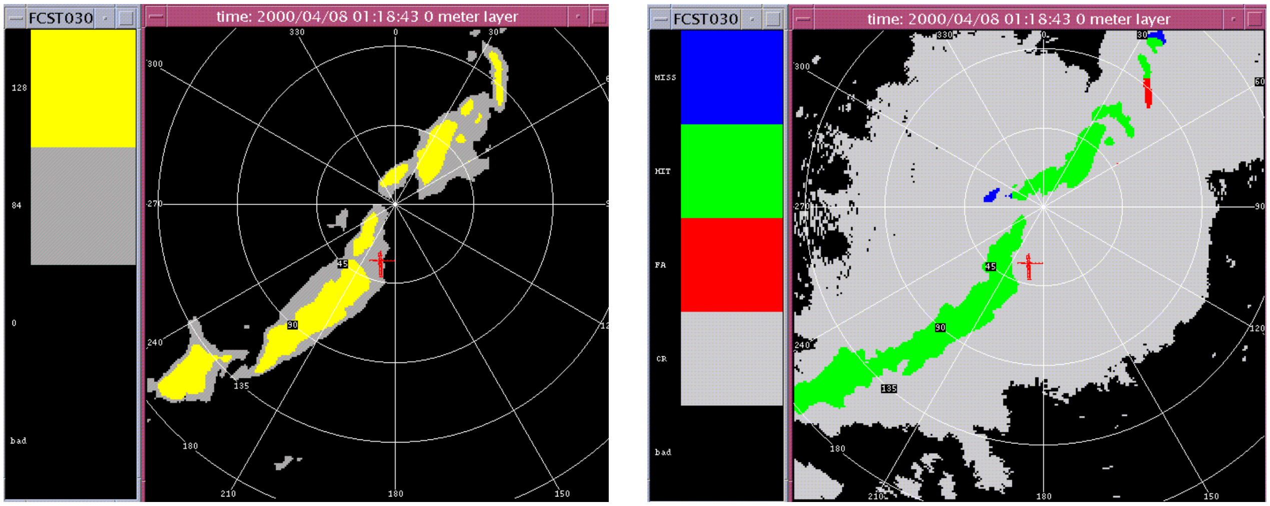


Figure 16. Example of the 30 minute forecast performance on 7 April 2000. (a) Image of the 30 minute forecast. (b) Forecascore plot of the 30 minute forecast performance at the same time.

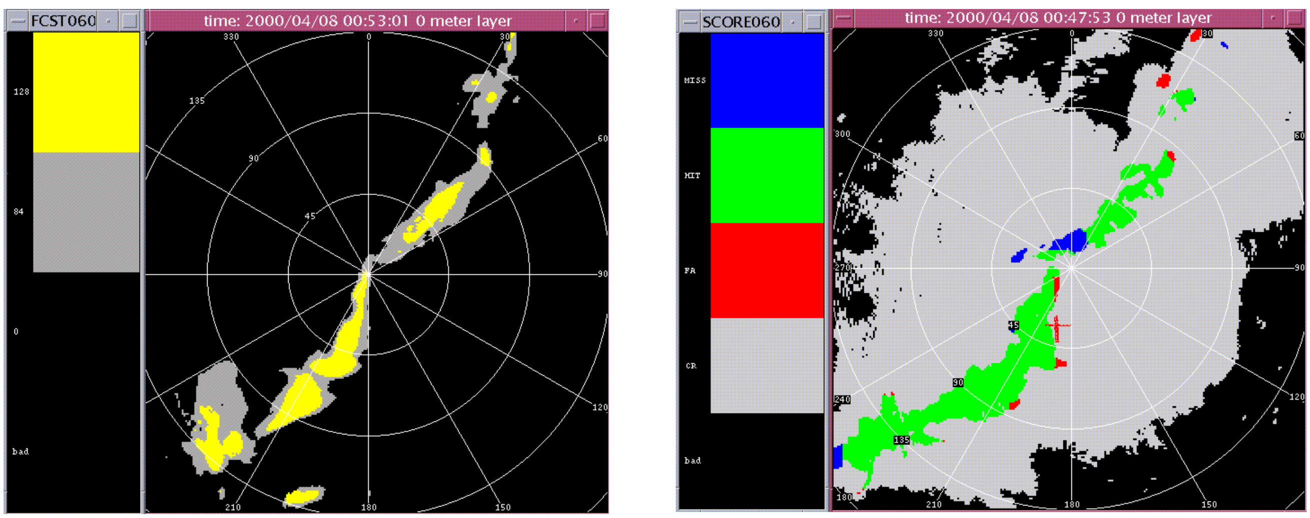


Figure 17. Example of the 60 minute forecast performance on 7 April 2000.(a) Image of the 60 minute forecast. (b) Forecascore plot of the 60 minute forecast performance at the same time.

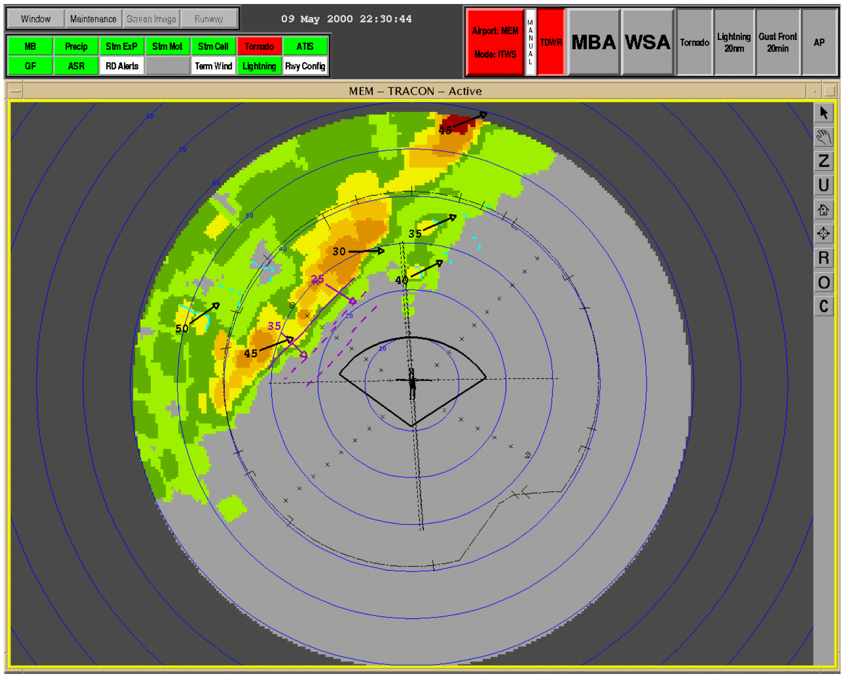


Figure 18. *Image of the ITWS SD illustrating the weather impact on 9 May 2000.*

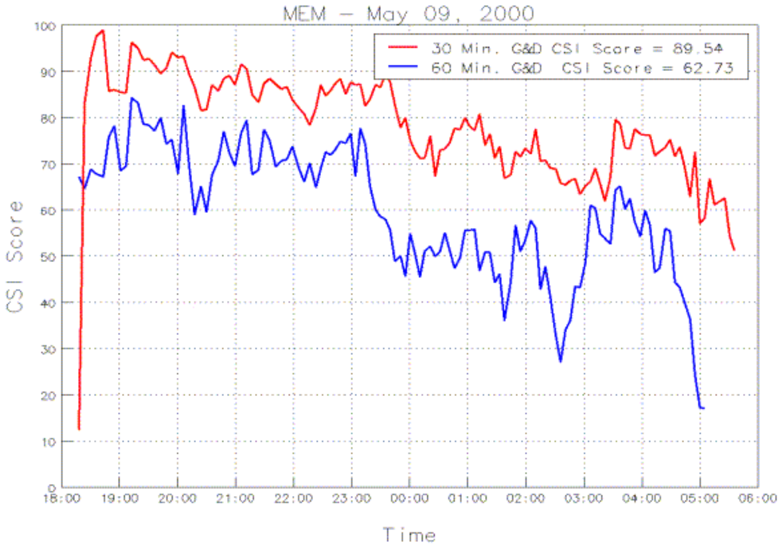


Figure 19. Timeseries plot for 9 May 2000. The red curve indicates the 30-minute forecast accuracy scores, while the blue curve indicates the 60-minute scores.

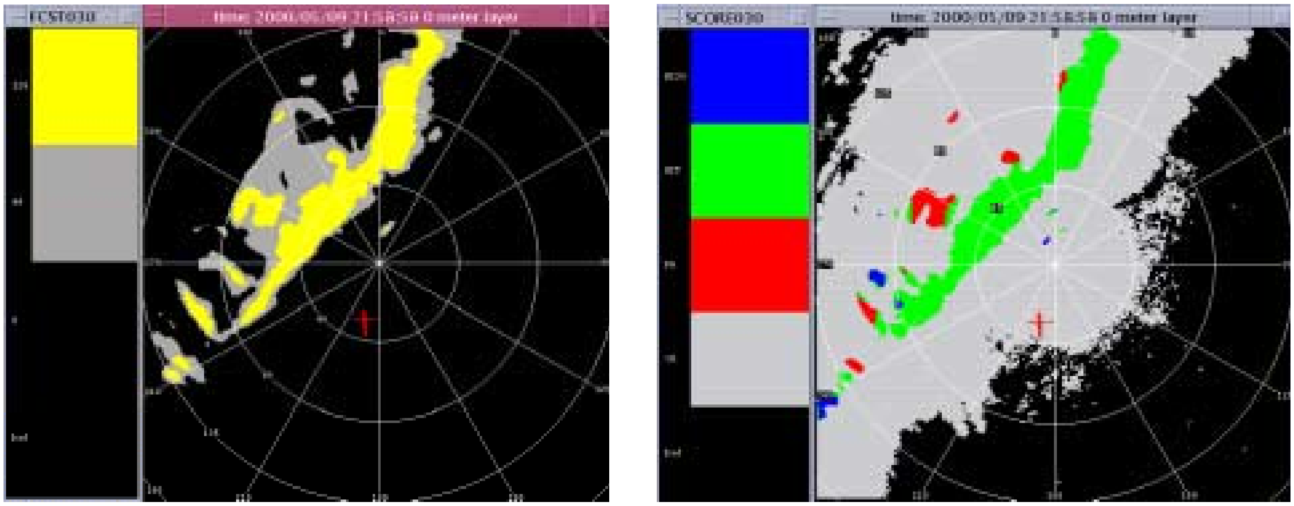


Figure 20. Example of the 30 minute forecast performance on 9 May 2000. (a) Image of the 30 minute forecast. (b) Forecascore plot of the 30 minute forecast performance at the same time.

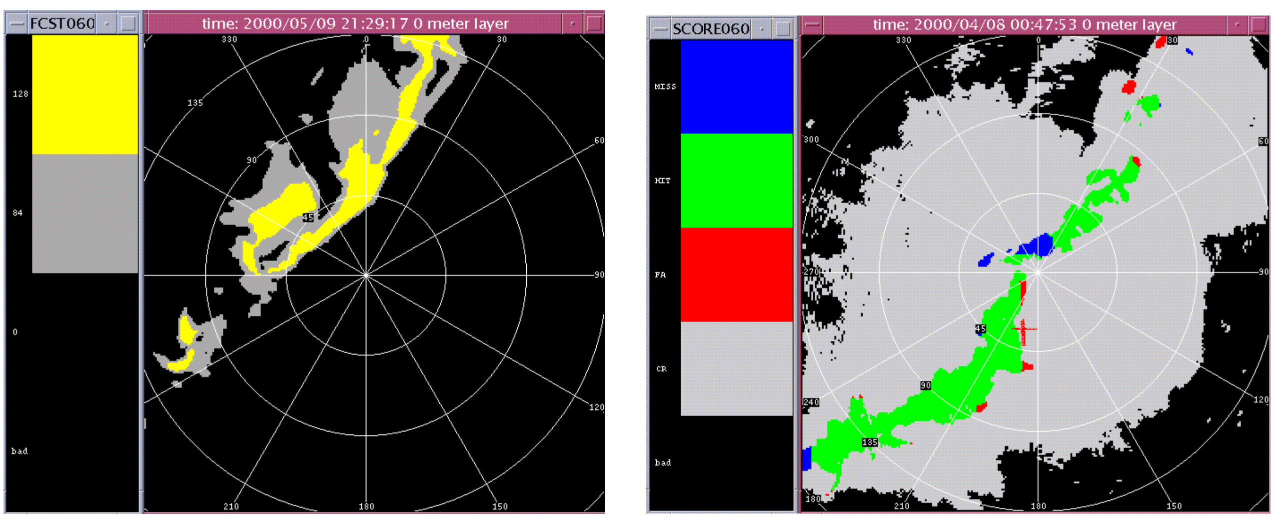


Figure 21. Example of the 60 minute forecast performance on 9 May 2000. (a) Image of the 60 minute forecast. (b) Forecascore plot of the 60 minute forecast performance at the same time.

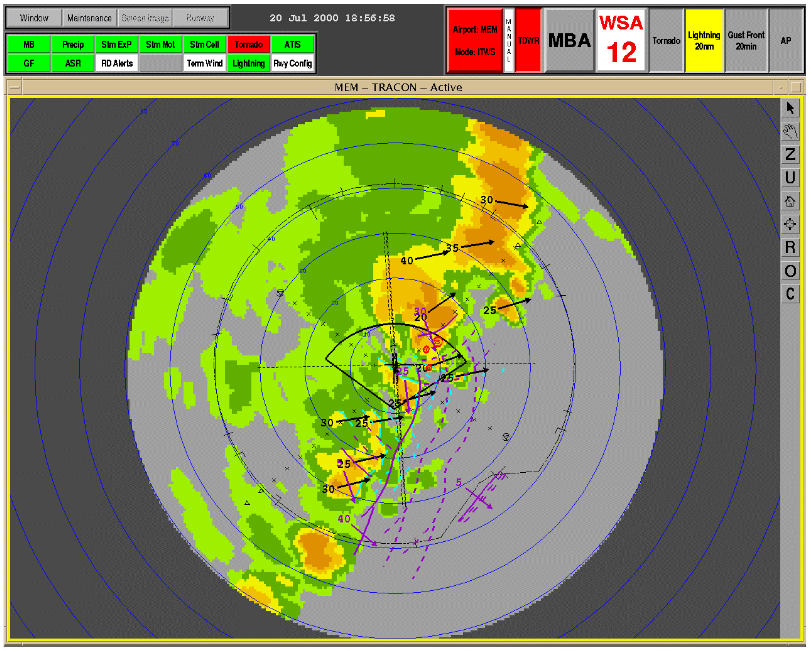


Figure 22. Image of the ITWS SD illustrating the weather impact on 20 July 2000.

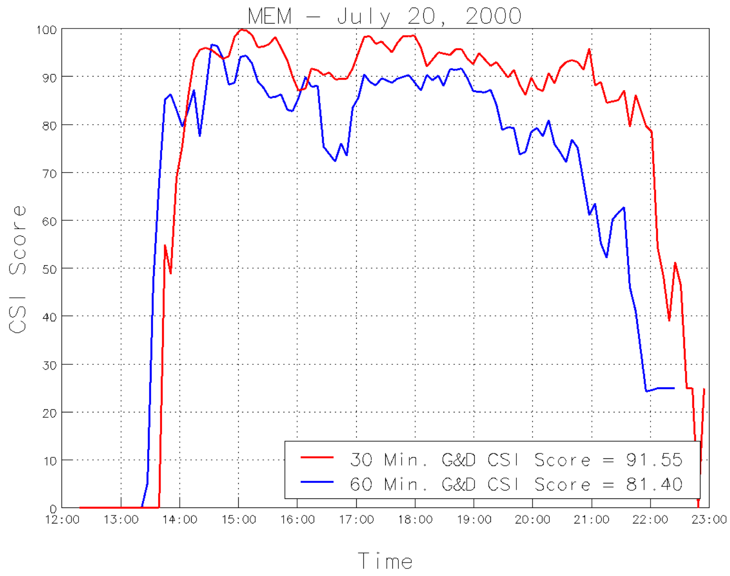


Figure 23. Timeseries plot for 20 July 2000. The red curve indicates the 30-minute forecast accuracy scores, while the blue curve indicates the 60-minute scores.

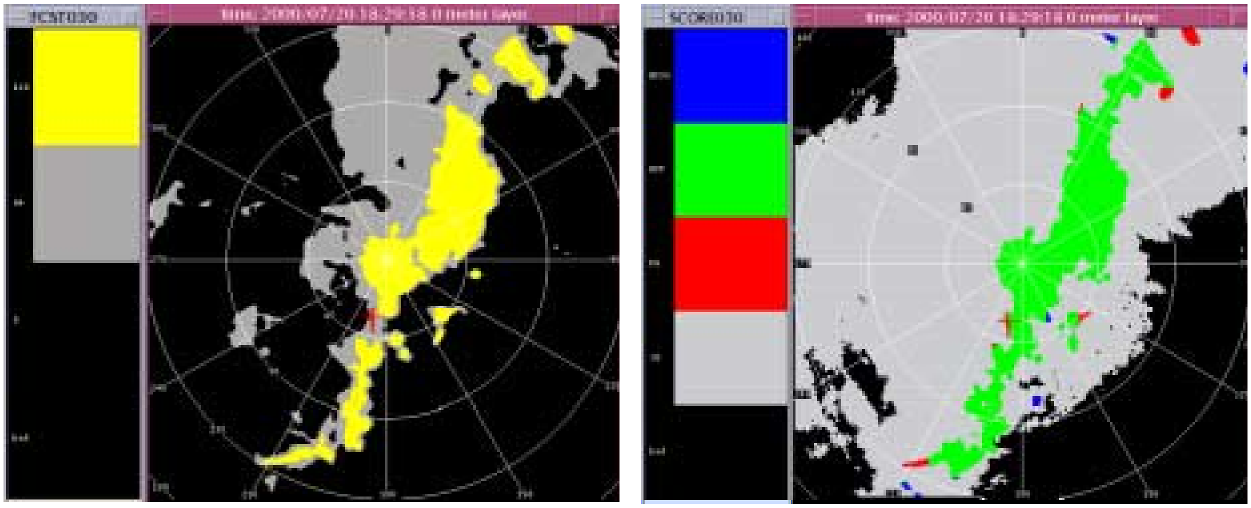


Figure 24. Example of the 30 minute forecast performance on 20 July 2000. (a) Image of the 30 minute forecast. (b) Forecascore plot of the 30 minute forecast performance at the same time.

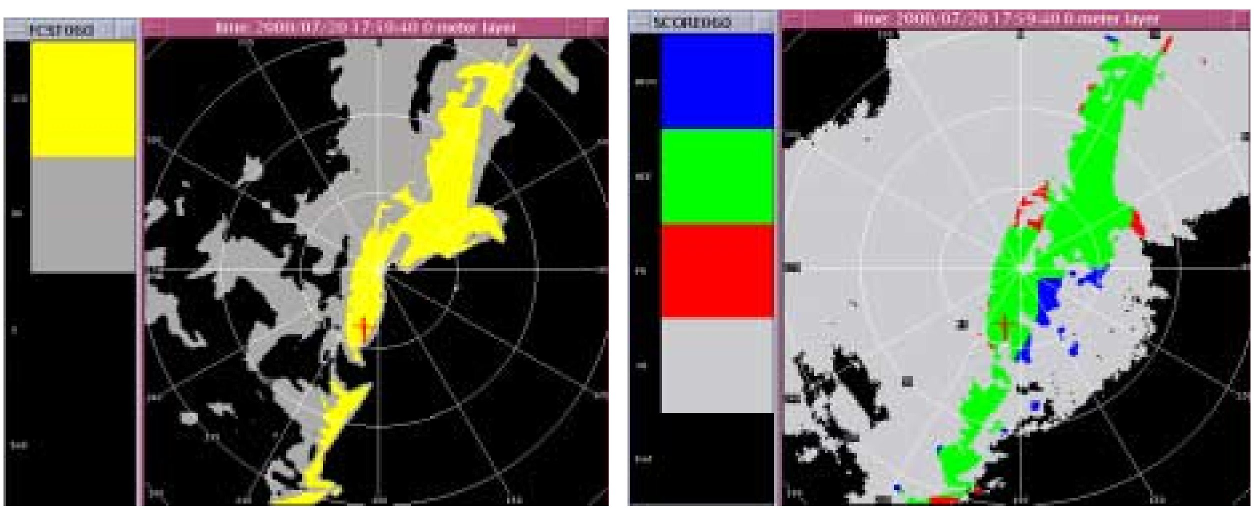


Figure 25. Example of the 60 minute forecast performance on 20 July 2000. (a) Image of the 60 minute forecast. (b) Forecascore plot of the 60 minute forecast performance at the same time.

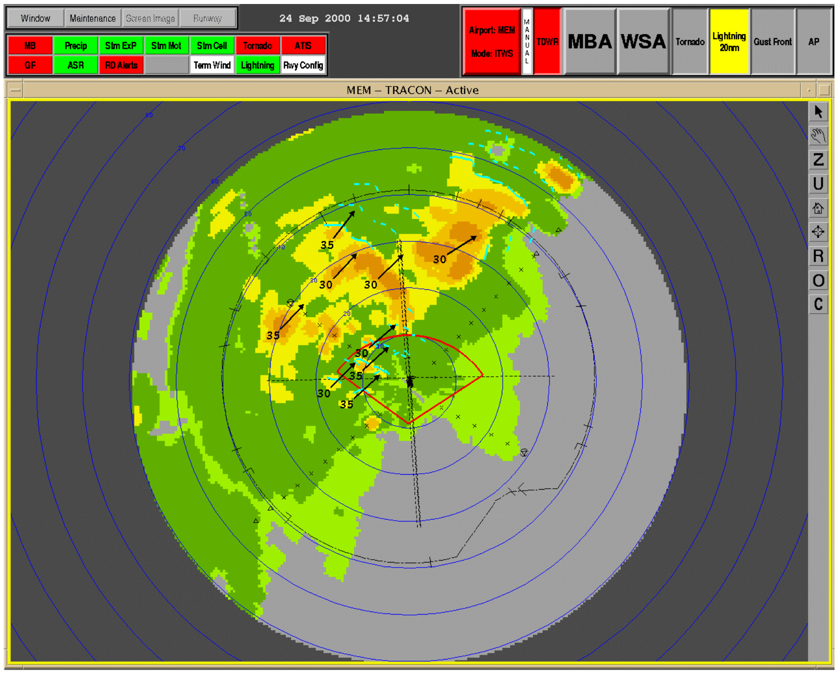


Figure 26. Image of the ITWS SD illustrating the weather impact on 24 September 2000.

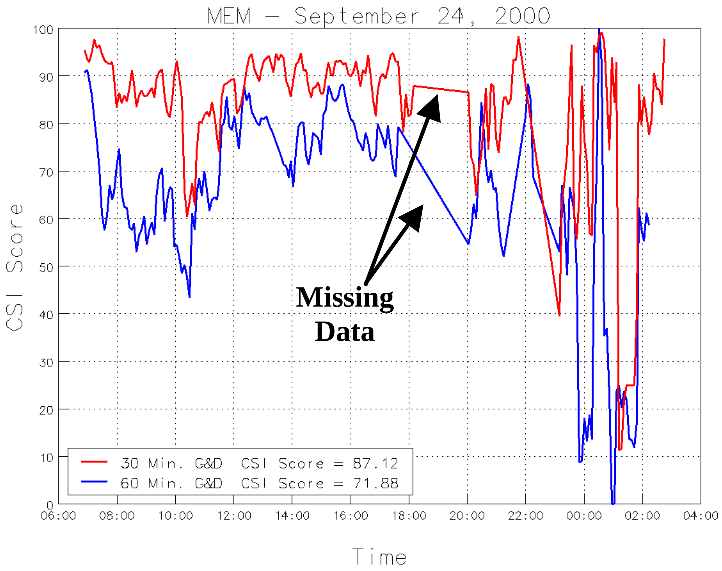


Figure 27. Timeseries plot for 24 September 2000. The red curve indicates the 30-minute forecast accuracy scores, while the blue curve indicates the 60-minute scores.

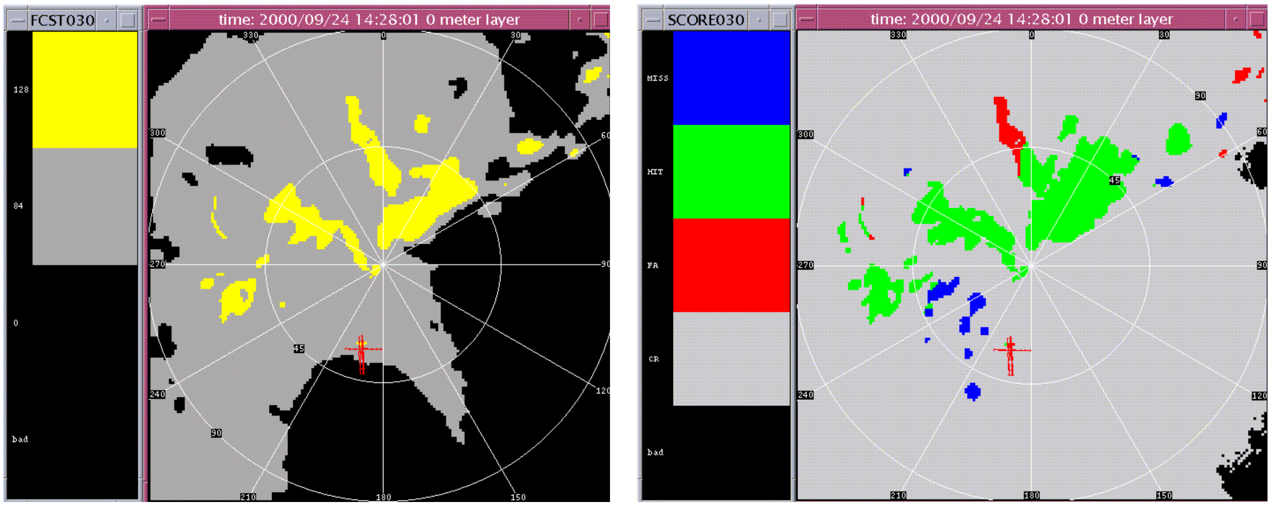


Figure 28. Example of the 30 minute forecast performance on 24 September 2000. (a) Image of the 30 minute forecast. (b) Forecascore plot of the 30 minute forecast performance at the same time.

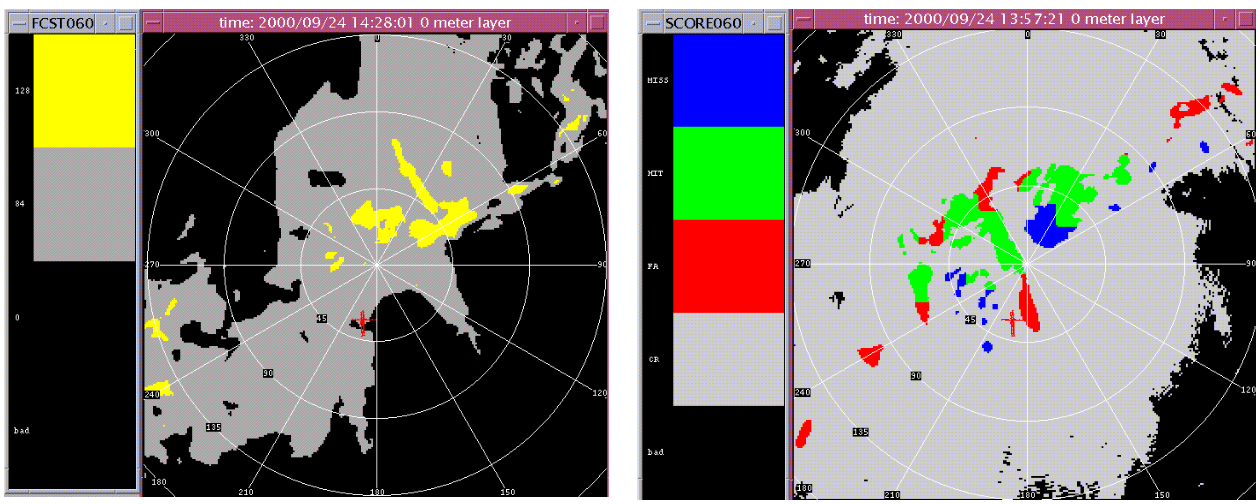


Figure 29. Example of the 60 minute forecast performance on 24 September 2000. (a) Image of the 60 minute forecast performance. (b) Forecascore plot of the 60 minute forecast performance at the same time.

4. DEMONSTRATIONS IN DALLAS AND ORLANDO

While the TCWF Assessment was taking place in MEM, real-time demonstrations in Orlando and Dallas continued. The algorithm was updated on 26 April 2000 at MCO and on 29 April 2000 at DFW. User comments regarding the better resolution and new look of the display are discussed in following sections. MCO and DFW events are summarized in the appendices (Tables D-1 and E-1, respectively), including the dates and times of the events, weather scenarios, TCWF performance, and any benefits or problems noted with the algorithm. Daily forecast statistics were also computed for MCO and DFW, and can be found in Tables D-2 and E-2, respectively. As for Memphis, the performance statistic tables include the total number of hours and pixel amounts for each event. This is important because days on which there is little weather (low pixel counts) are not as significant as those days with heavier weather. Three different scores are presented, as well as a forecast bias number. A full explanation of the forecast scoring categories can be found in Appendix B.

4.1 ORLANDO (MCO) PERFORMANCE RESULTS

The MCO convective storm season started about three weeks later than normal this year. The season was definitely drier and less severe than in years past. Areal coverage of storms was much less, most likely a direct result of fewer sea breeze collisions. This was likely due to either easterly or westerly predominate flow that minimized the formation of one of the sea breezes. Rainfall amounts were well below average for May - August with September being the only month that rainfall was slightly above average.

We studied TCWF performance for MCO in the same manner as MEM. Unlike MEM and DFW, air mass storms dominate the MCO weather scenario. For this reason, the 60 minute "User" scores shown in the bar chart in Figure 30 are typically lower than those for MEM or DFW. The lack of large-scale organization, combined with the slow-moving nature of the storms, made it difficult for the product to provide 60 minute forecasts above the 50% accuracy level. However, the 30 minute forecast accuracy performance numbers were quite good, with typical values near and above the 80% mark. Many of the problems noted from MCO were caused by the algorithm moving the storms either too quickly or in the wrong direction. These issues were studied during the Assessment and are addressed in Chapter 5.

The MCO users definitely preferred the new SD-based display to the previous web browser version, because of its dependability. (The web-based display would apparently “hang” on occasion.) The SD is also in a format that they are very familiar with, similar to that of ITWS. Overall, the users realize that TCWF does not currently do that well with airmass situations, particularly with the initiation/decay stages of storm evolution. There were several days when the MCO users had positive comments regarding TCWF, specifically the Jacksonville (ZJX) Air Route Traffic Control Center (ARTCC) users, but for the most part they will not gain a great deal of benefit from the product until explicit growth and decay forecasts are added.

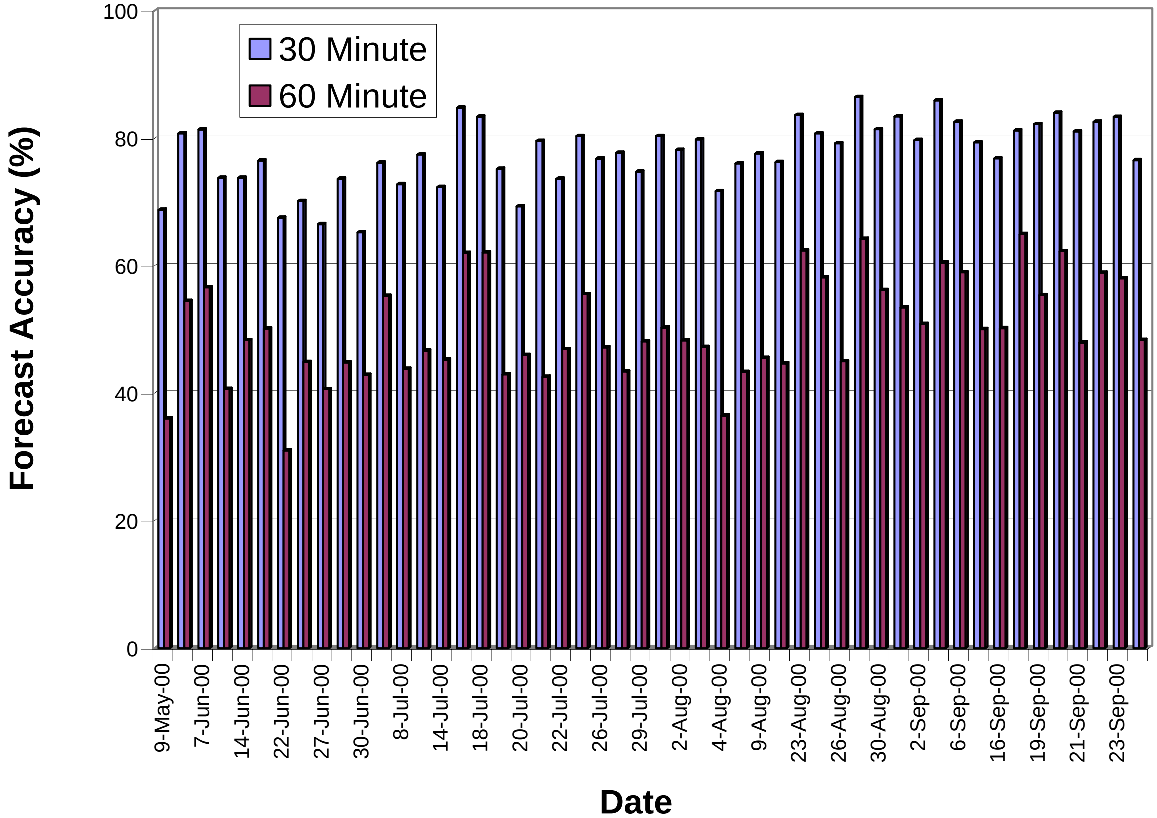


Figure 30. MCO performance scores for the 2000 cases. Blue bars indicate the average 30 minute forecast scores while the red represents the average 60 minute scores.

4.2 DALLAS FORT-WORTH (DFW) PERFORMANCE RESULTS

TCWF demonstrations in DFW continued for the third year, with DFW experiencing the longest dry spell in recorded history at the airport from 1 July to 22 September. The summer of 2000 had 46 days of ≥ 100 degree temperatures, so weather events were scarce. Table E-2 shows the average scores (since the upgrade of the TCWF algorithm) for the events in DFW that were deemed significant, through the end of September. The 30-minute and 60-minute "User" scores charted in Figure 31 indicate that all but a few 30-minute scores were close to the 80% accuracy mark, with several events even higher. (The few cases with lower scores had short-lived, isolated convection.) The majority of the 60-minute scores were between 40% and 60% forecast accuracy levels.

The staff at the DFW ITWS prototype site polled several different users on the updated TCWF product. The TRACON users like the better resolution of the TRACON forecast. They indicated that they like the new display much better. (However, there are still some people that would like to see different colors used for the forecast product) After speaking with some of the meteorologists from the CWSU, it became clear that they really like the TCWF product. They particularly like the new display and indicated that it has made a big difference in the usefulness of the product. The CWSU staff feel that they get more use out of the product now than they did before the upgrade, noting the finer resolution was an improvement. They didn't have an opinion on the change of scoring numbers, but they feel the forecasts themselves have improved. The meteorologists further commented that they almost always use the TCWF product for their weather briefings.

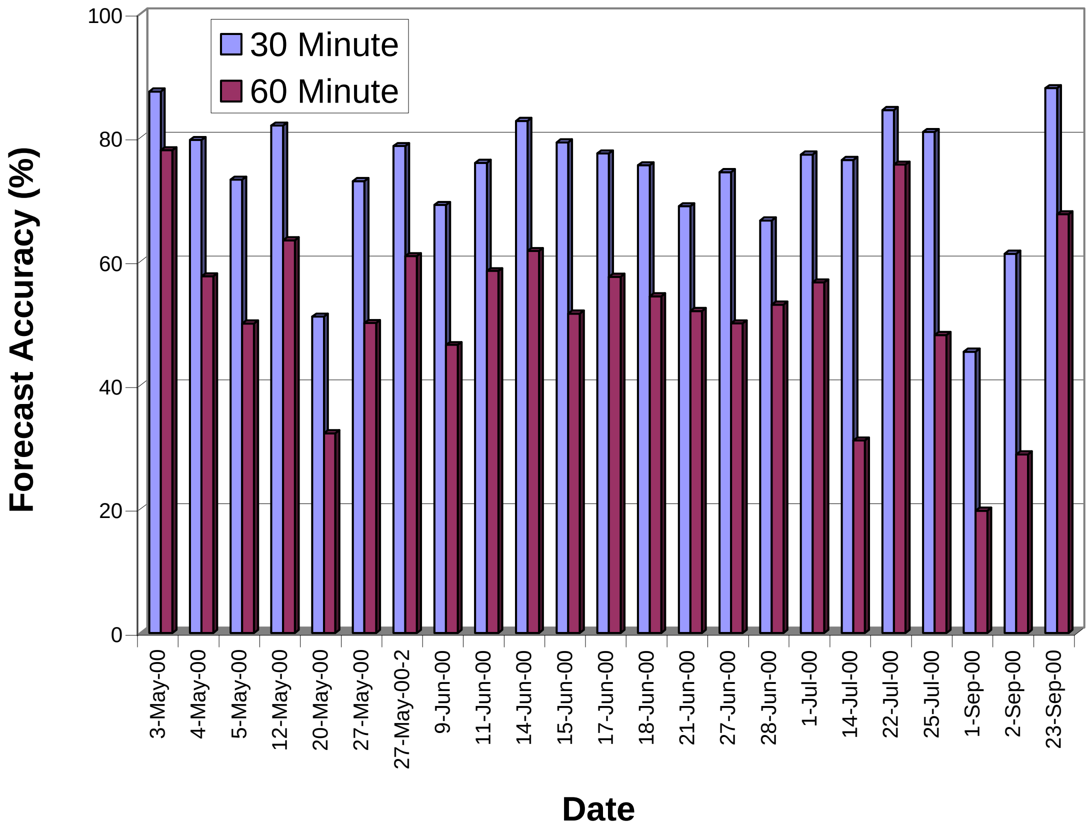


Figure 31. DFW performance scores for the 2000 cases. Blue bars indicate the average 30-minute forecast scores while the red represents the average 60 minute scores.

5. PROBLEMS DURING ASSESSMENT

5.1 ADDRESSING PROBLEMS AT ALL SITES

The field sites routinely send out operational status reports summarizing weather events, noting algorithm performance, problems, and user benefits. From these updates, the TCWF team is able to log problems, analyze the data and provide feedback/solutions. Details of the various noted problems are discussed in the following paragraphs.

5.1.1 Artifact Problems

Forecast artifacts were noted with the algorithm on two Memphis days, 27 April and 25 May 2000, and one Dallas case, 20 June 2000. The two days from Memphis exhibited very similar artifact features (elongated narrow loops in the forecasts) while the Dallas case showed something different (blooming cells through the 60 minute forecast). To resolve the problems, a study was done on the three cases as well as a non-problematic line storm case from DFW (1 June 1996), to understand how the artifacts could be eliminated.

Analysis determined that these artifacts lasted only one or two scans (6-12 minutes) and were related to rapid changes in the tracker motion field, often caused by new growth that was not smoothed by the large-scale filter. Testing one of the Growth and Decay Tracker parameters for heavier time smoothing eliminated the artifacts for the Memphis cases (see Figures 32 and 33) and improved the Dallas case (see Figures 34 and 35). This time weight parameter uses a percentage of the current and prior vectors to advect the weather. Analysis showed that variability in the current vectors contributed to the artifact problem. Previously, the parameter was set to 25%, i.e., prior vectors would be weighted 25% while the current vectors were weighted 75%. The parameter was tested at 50%, 60%, 65%, 70% and 75%. Weighting the prior vectors 70% and the current vectors 30% proved to be the optimal choice to rectify both the Memphis artifact problems and the blooming cell problem shown in Dallas.

With the optimized setting, the vectors react less quickly to a changing environment, but this is preferable to the chaotic vectors that led to the appearance of the artifacts in the forecasts. As a control, we checked the performance of the new time weighting parameter on the 1 June 1996 case. The average 60-min box score changed negligibly from 51.90 (previous 25% setting) to 51.92 (current 70% setting). The time series in Figure 36 shows that at times a penalty is paid for the heavier time smoothing, but at other times there are advantages or basically no differences. The new parameter was released to sites on 10 July 2000.

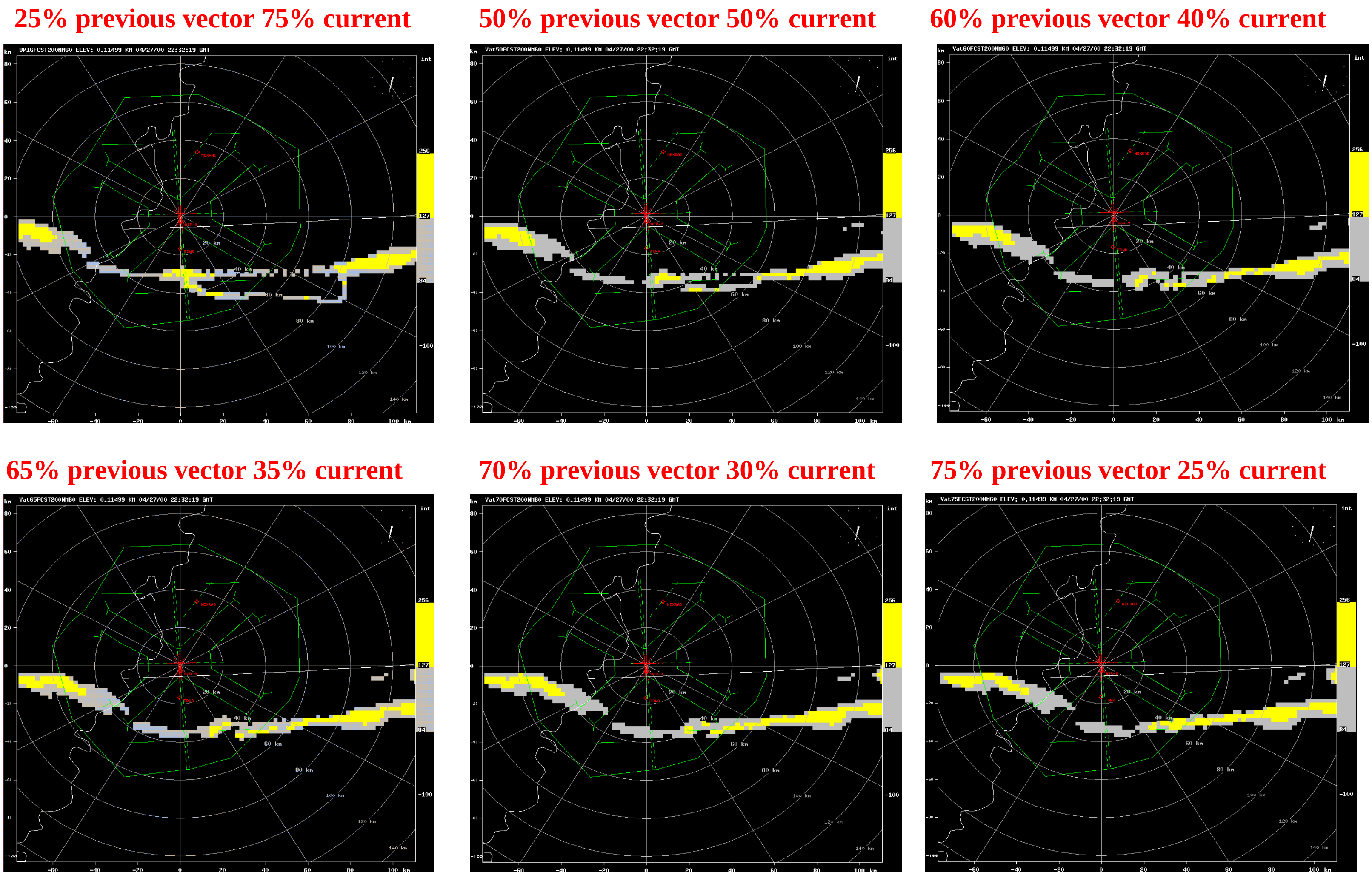


Figure 32. Memphis artifact case, 27 April 2000. Testing was done for heavier vector time weighting. The 70% prior vector, 30% current vector setting was chosen to eliminate the artifact and improve the forecast accuracy.

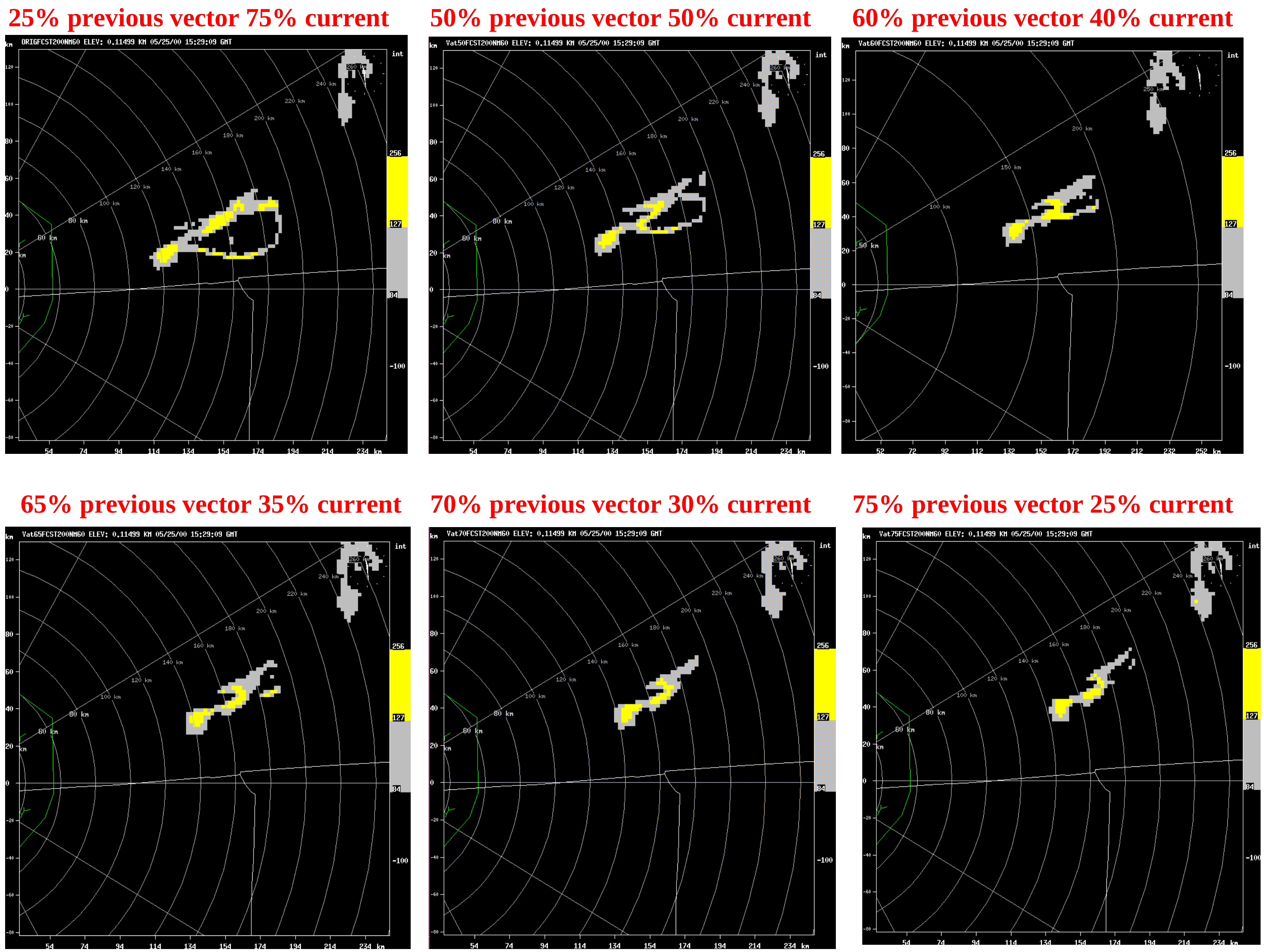


Figure 33. Memphis artifact case, 25 May 2000. Testing was done for heavier vector time weighting. The 70% prior vector, 30% current vector setting was chosen to eliminate the artifact and improve the forecast accuracy.

DFW-20 June 2000 Original Forecasts (25% previous vector, 75% current)

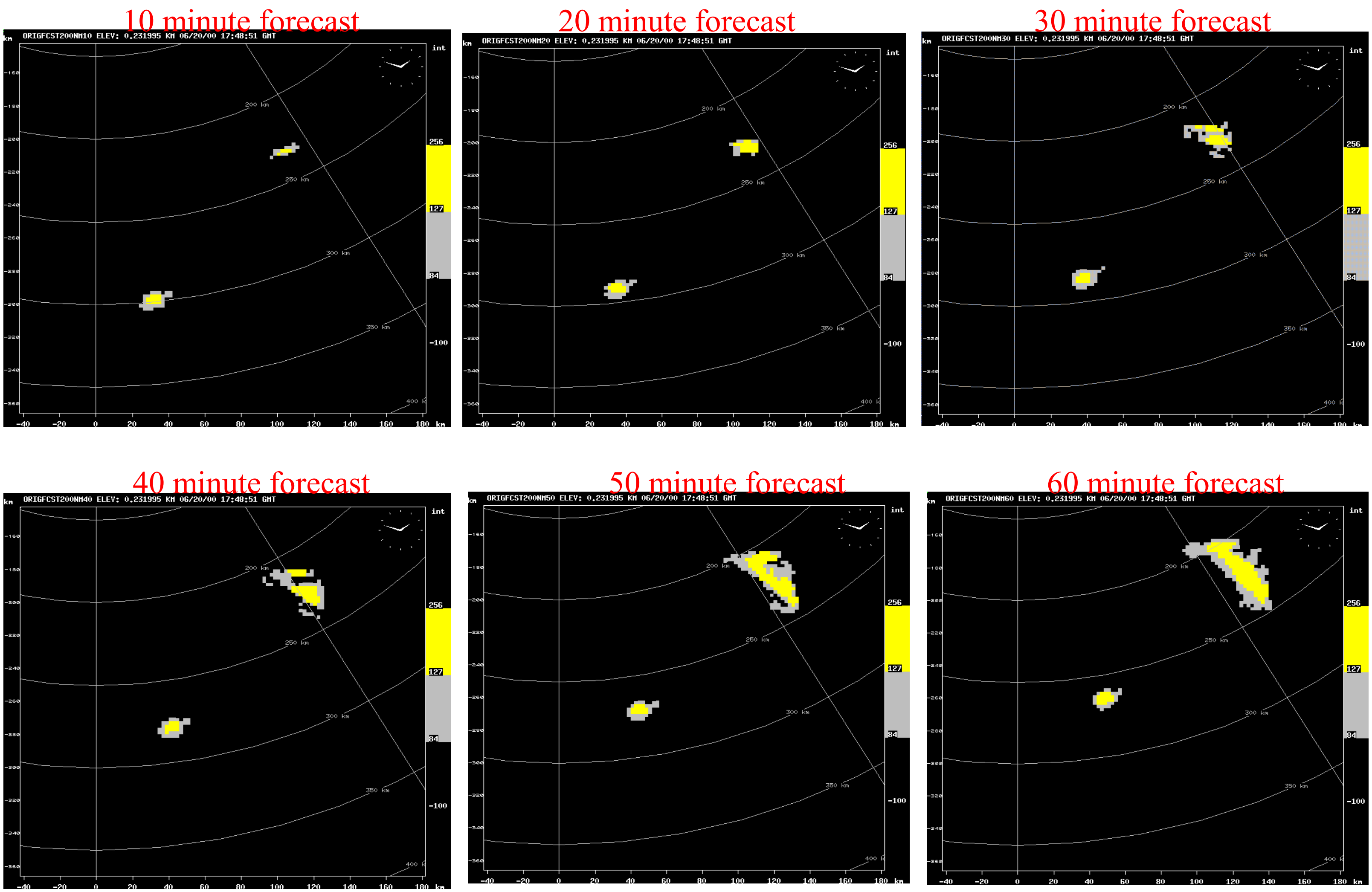


Figure 34. Blooming cell case from DFW- 20 June 2000. This example shows how the cell to the Northeast grew rapidly over the 60 minute forecast period. Sporadic flaky vectors proved to be the culprit. The problem was improved by heavier time weighting of the vectors and improvements can be seen in Figure 35

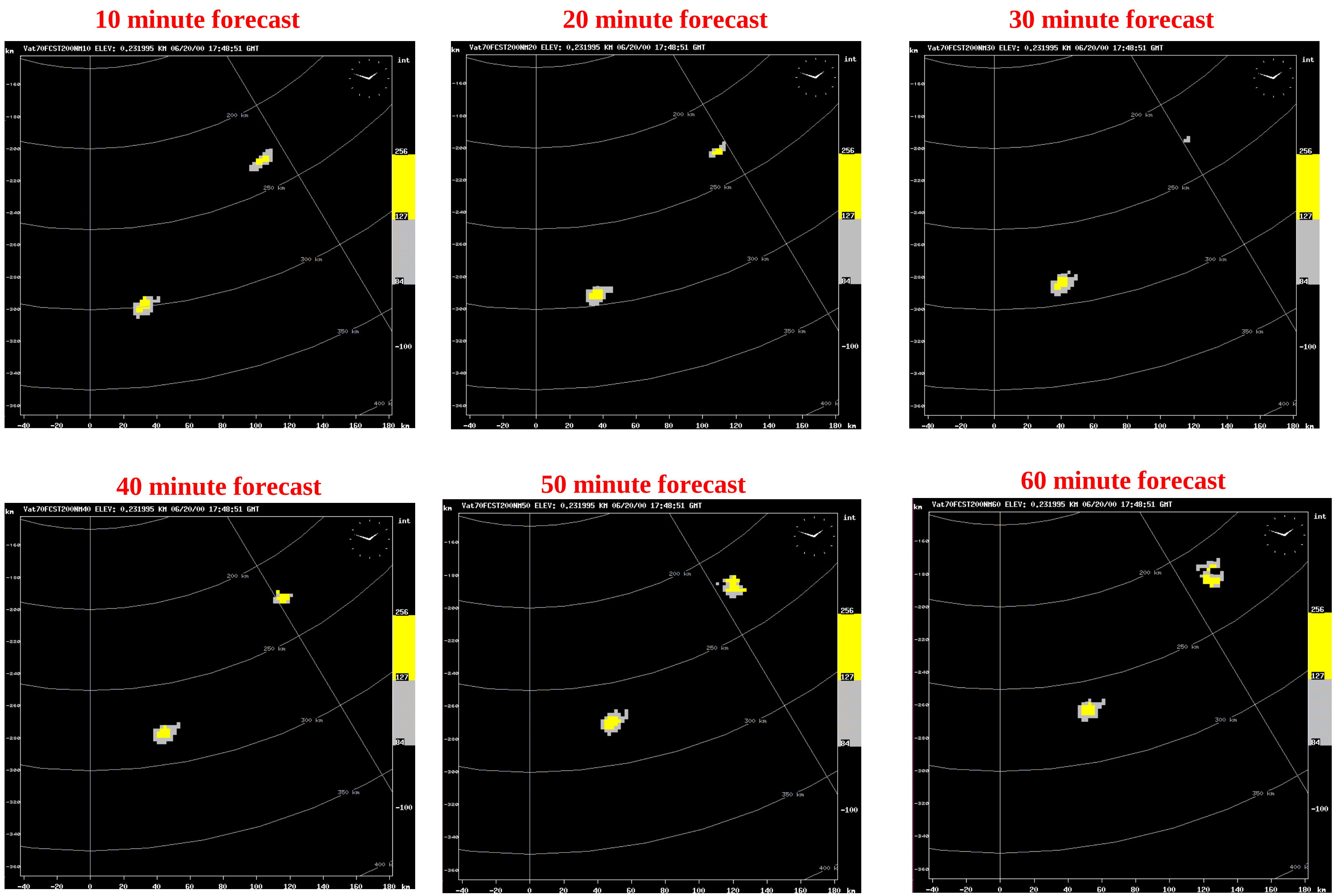


Figure 35. Correction of blooming cell in DFW – 20 June 2000 after time weighting parameters were increased. The selection of the tracker parameter setting of 70% prior vector and 30% current vector improved forecasts for the longer forecast periods.

Figure 36. Timeseries plot of Box Scores for various vector time weight settings on 1 June 1996 in DFW. The runs were done with the original weighting of prior vectors at 25% up to 75% (Vat75- Previous vectors at 75%). The selection of the tracker parameter setting of 70% prior vector and 30% current vector has eliminated the growing artifact and improved the forecasts.

5.1.2 Errors in Direction or Speed of Storm Movement

The Orlando test site experienced problems with forecast vectors moving the storms in the wrong direction, or moving storms that were generally stationary. Table 6 lists the 9 days in 2000 on which site personnel noted that the algorithm forecasted significant weather with an incorrect direction or speed. There were markedly fewer complaints about this type of problem than in 1999. The improved performance was due primarily to the increased resolution of the precipitation grid from 4-km to 1-km. The slow moving nature of a majority of Orlando storms requires increased resolution to resolve the speed and direction of storm motions. Although the storm motion problem days were limited, they are still a significant problem. We examined 5 of the problem days in detail to determine the nature of the tracking problems, and if parameter adjustments might be useful in eliminating or reducing the tracking difficulties.

First, all of the days were rerun using the latest optimization parameters for TCWF (specifically increasing the local weighting factor to 0.7 as discussed in Section 5.1.1). This control run illustrated that the local weighting factor helped to remove the directional bouncing indicated in the site comments on 3 June 2000. The air mass nature of storms on all these days (rapid, small-scale growth and decay) were not captured well by the TCWF algorithm and scores were consequently quite low. Future improvement will better enable the algorithm to predict these rapidly changing small-scale features more accurately. In the near term, we tried to focus on cells or regions of cells that could have been predicted better over 30-minute time frames. The two main causes of the incorrect projections were found to be a) over-filtering and b) use of a quality control constraint based on the direction of the global vector.

TABLE 6
Air-mass Vector Problem Days in MCO during 2000

Date	Type	Vector Error	Site Comments
6/3/00	Airmass	Direction & Speed	Initial forecasts moved cells rapidly East then North, then NNW. Cells were primarily stationary.
6/7/00	Airmass	Direction	TCWF showed SE motion throughout the image that was correct for most storms on this day. However, a group of cells that hit the airport actually moved North and West.
6/17/00	Airmass	Speed	Direction was good; however the advection was too fast especially for the first wave.
7/20/00	Airmass (organized)	Direction & Speed	TCWF showed thunderstorms moving SSW when the actually remained stationary or moved slightly East.
8/5/00	Airmass	Speed	Motion was mostly stationary but TCWF moved the storms.
8/9/00	Airmass and Line	Direction	TCWF moved western cells to the SE while they were actually building East.
9/7/00	Airmass	Speed	Movement was too fast while most of the storms were stationary.
9/21/00	Airmass (organized)	Speed	Direction was good but motion was too fast.
9/29/00	Airmass	Direction	TCWF moved storms East and ENE but storms were either stationary or drifted slowly West.

5.1.3 Over-filtering

TCWF captures the envelope motion of storms by tracking the large-scale filtered (13x69-km) precipitation image. This technique works extremely well during large, organized storm events, but the filtering is mismatched when small isolated cells are the primary form of convection. Figure 37 shows (a) the raw VIL field for 6/7/00 and (b) the corresponding large-scale filtered (13x69) image. Notice that the edges of the filtered regions are irregular and jagged. Rapid growth and decay causes the irregularities to vary significantly from time period to time period. In addition, because the high signal areas are so small, the automated track levels are very low. This causes the tracker, which tracks the top 40% of the pixels in an image, to follow the motion of these erroneous edges instead of the core of the storms. We performed a number of experiments testing smaller filter sizes and determined that a 13x13-km filter tracks the air mass storms most reliably.

5.1.4 Global Vector Constraint

The primary quality control check in the correlation tracker is to compare the “global vector” with each coarse raw vector. The global vector is calculated by cross-correlating 75% of the total image to determine the overall motion of all storms in the image. Raw vectors (in our case, these vectors are calculated every 14-km) are dependent on the global in two ways as illustrated in Figure 38 (a) and (b). First, the global vector is used to pre-position the correlation grid for local vectors; the grid is shifted to start at the global vector position Secondly, the determined raw vector direction is compared with the global to be within “n” degrees (±70 degrees in the current parameter setting). In the case where all the storms in the image are forced by the same synoptic forcing, the global is an effective tool in removing errant vectors. As shown in Figure 39, the gold colored vectors have had no global constraints applied and the vectors vary greatly in direction and magnitude in regions near the weather. In air-mass situations, prevalent in Orlando, storm movement can often be controlled by meso- and micro-scale forces that vary throughout the forecast region. Determining one vector to characterize all these movements would be impossible.

We have begun examining a new technique for reducing errant vectors without relying on the global vector direction constraint. The new technique utilizes the variation of the local correlation field to constrain the search for the appropriate vector displacement. Figure 40 shows an example correlation box field. The center bin (shaded) represents a displacement of (0,0) between the two correlation images. Correlating two identical images would result in a correlation of 1.0 in the center bin. The standard method used to find the true displacement vector has been to find the overall maximum in the correlation field within the designated search space. This method works quite well for line storms where the peak signature is quite clear. In the case of isolated storms, however, multiple peaks may form in the correlation surface making the selection of the best overall peak problematic.

Looking at the example in the figure, the (0,0) correlation is 0.68 and the two highest peaks in the correlation field are 0.80 and 0.81 at (-3, -3) and (+3, +3), respectively. The current method of choosing the vector displacement is to find the maximum correlation value in the entire search box. Using this method we would determine the movement of this grid box to be 4.24 km at 45 degrees. Notice, however, that the relative peaks as we move out from the center are located in the opposite direction of the overall maximum. The new "correlation restriction" technique takes advantage of this natural "fingering" to choose a more relevant vector displacement of 4.24 km at 225 degrees (-3, -3). A new parameter was introduced to the tracker called corrRate, defined to be the minimum correlation increase necessary to choose a new maximum.

Referring to Figure 40, the initial correlation match begins at (0,0) [0.68 correlation] and steps out 1 pixel from the center in all directions. In order to choose a new maximum, the correlation must now be [0.68 + corrRate * pixel range] (for this example corrRate = 0.01), so a shift of one pixel would be 0.69. If there are multiple values equal to or greater than the threshold value then the largest is chosen. For our example, the first tier results in a relative maximum at (-1,-1) of 0.71. As the process progresses, it becomes increasingly harder to shift the direction away from the current position. By the third tier in our example the displacement from (-2, -2) to the maximum that would be chosen with the traditional technique (+3, +3) would require a correlation of [0.78 + corrRate * 7.07 pixels] or 0.85. As shown in Figure 39, instituting the correlation restriction (white vectors) leads to a well-behaved vector field, without a reliance on the global vector.

Comparison results from five air-mass days (MCO – 2000) are shown in Figure 41. Note that in all cases the overall binary scores are improved, although there are times within the data where the global constraint performs better than the correlation restriction. However, the overall improvement suggests that the correlation restriction may represent an improvement in air-mass situations.

(a)

(b)

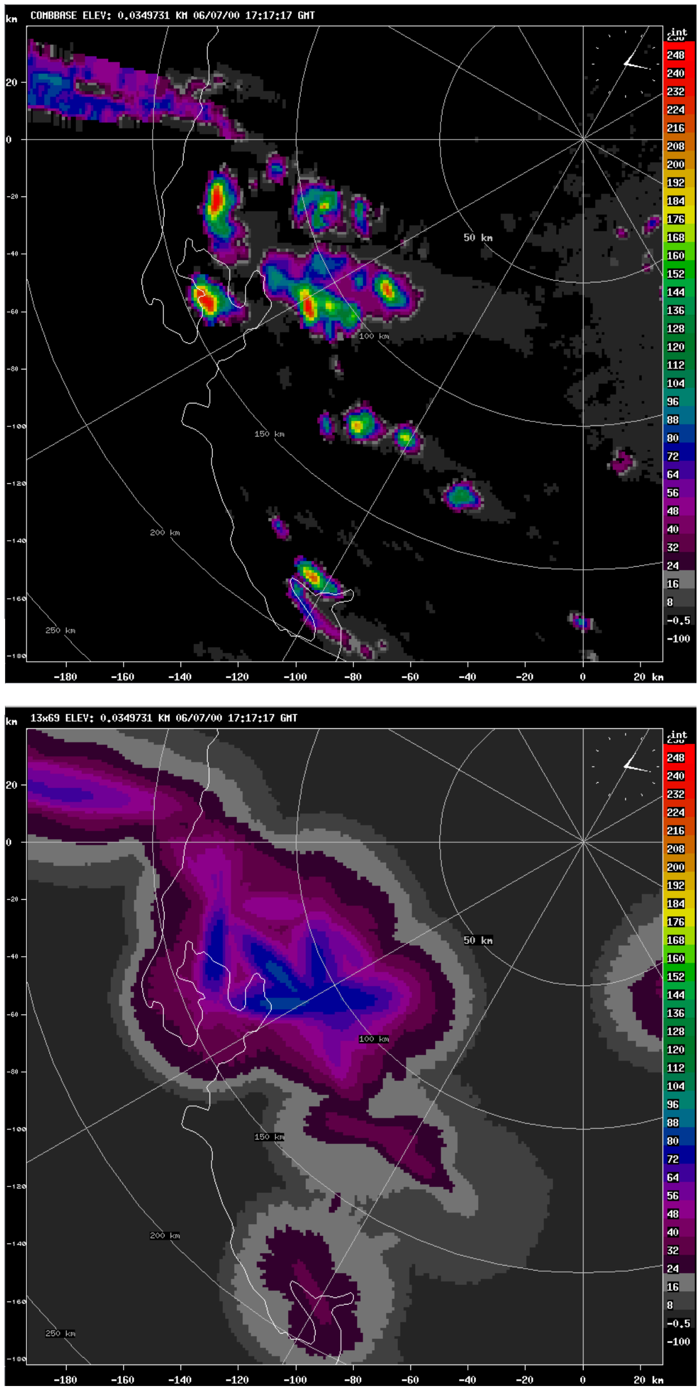


Figure 37. Comparison between raw VIL and filtered VIL data. (a) Raw VIL data from MCO on 7 June 2000 1717 GMT (b) 13x69 Filtered data at same time period.

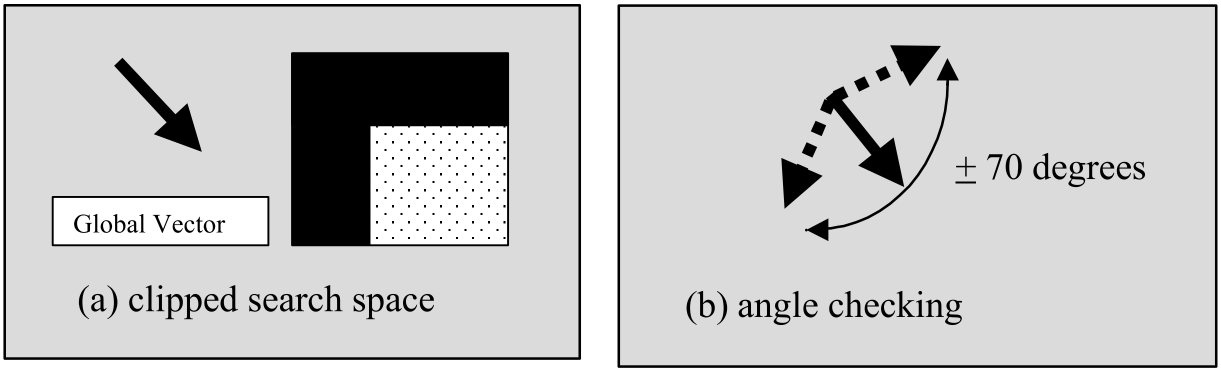


Figure 38. Current environmental constraints on coarse vectors imposed by global vector. (a) Pre-positioning and clipping of search space, and (b) restricting coarse vector angles to be within tolerance of global vector angle.

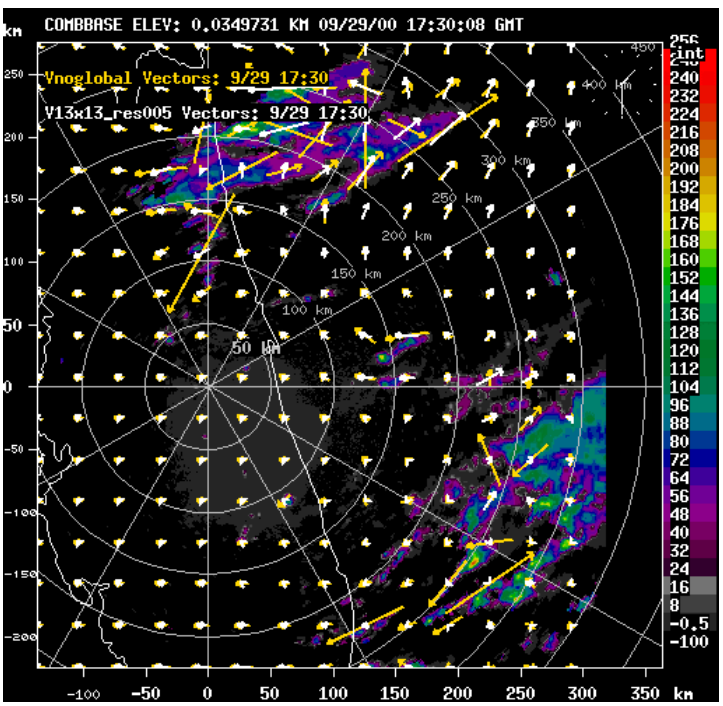


Figure 39. Precipitation image from 29 September 2000 (MCO). Gold vectors show 13x13 filtering with no global constraints applied, white vectors show the same filter utilizing the correlation restriction to replace global environmental checking.

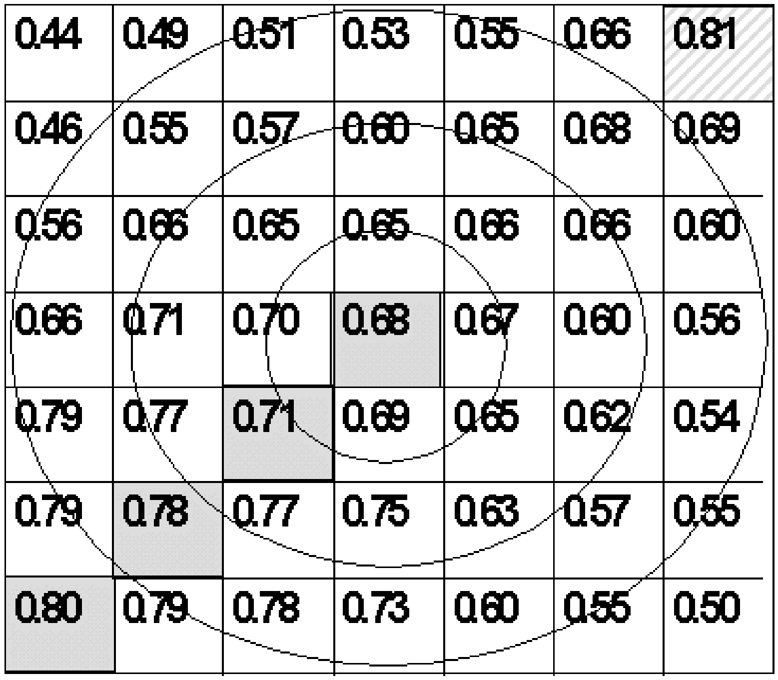


Figure 40. Illustration of the current (grey hatched) and correlation restriction (solid grey) techniques of determining the appropriate displacement vector from the 2-d correlation field.

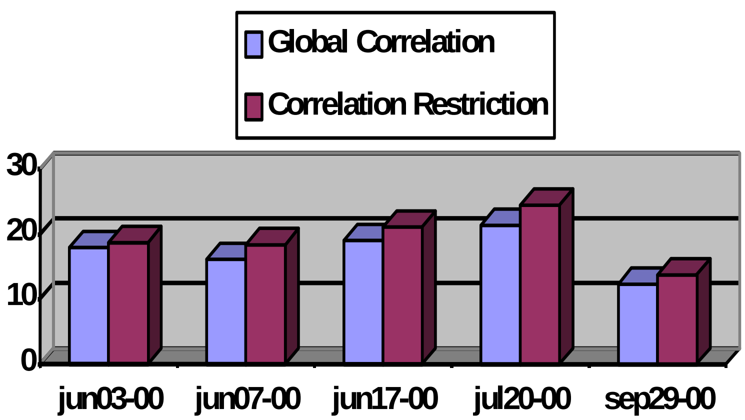


Figure 41. 30 Minute Binary Forecast Performance comparing global correlation and correlation restriction techniques.

5.2 BUG FIXES

5.2.1 Scoring

During the TCWF Assessment, a bug was discovered in the scoring software. The problem that affected the displayed scores was a result of the change in the forecast and the truth files. Previously, these grids had been the same size. Under the new system, with two grids (TRACON and 200nm) to be scored against one large truth file, the sizes of the forecast and truth files now differed. Instead of correctly matching the centers of the differently sized grids, the scoring process matched the lower left corners. This bug resulted in incorrectly classifying the weather to the north and east (upper right portion of the grid). With this bug fixed, the scores better matched the perceived forecast quality in the TRACON.

5.2.2 Situation Display

Occasionally the scores in the forecast accuracy panel on the Situation Display (SD) would briefly disappear. This turned out to be a problem with the SD falling behind in processing after being overwhelmed with the translation of the forecast streams. A multiplexor process was placed in between the translator and the SD to alleviate the problem.

Another SD related issue came up when the forecast button was not turning red on the Integrated SDs when the product became unavailable. This was due to the lack of any open Forecast windows on the Integrated SD. The SD would look for a window to update; if it did not find one, it would not continue. It is unlikely that the users would have noticed this bug because, by default, at least one window is always open.

6. SUMMARY

This report described the Terminal Convective Weather Forecast algorithm, developed under the FAA Aviation Weather Research Program by MIT Lincoln Laboratory as part of the Convective Weather Product Development Team. TCWF is proposed as a P^3I enhancement to the operational ITWS currently scheduled for deployment at major airports in 2002. Live demonstrations of the TCWF algorithm at the four ITWS prototypes (DFW, MCO, NYC, and MEM) have shown how robust and fundamentally useful the 60-min forecasts are for terminal and center operations. We have emphasized in this report the performance of the TCWF algorithm at Memphis, the only site where neither real-time testing nor operational use of the algorithm had taken place prior to 2000.

Prior to the Memphis 2000 Assessment, several upgrades were made to the TCWF algorithm based on prior testing at DFW, MCO and NYC. The Assessment began on 24 March 2000 and ran through the end of the fiscal year (30 September 2000). ITWS prototype site personnel watched the algorithm very closely, and discovered a couple of problems which were analyzed and fixed. Summaries of all the operationally important days and performance analyses for each were provided based on the detailed site logs - not only at MEM, the primary Assessment site - but at DFW and MCO as well. The performance of TCWF was excellent on the large scale, organized systems it was designed to predict, and the software was extremely stable during the Assessment.

The TCWF makes very useful - but still not perfect - 1-hour forecasts. Forecasting new growth and subsequent decay of large-scale storms is a very high priority for future research. We have not done well at tracking small-scale airmass storms (e.g., in Orlando) with TCWF's elliptical filtering and tracking designed for large-scale systems. Part of this problem was analyzed and potential solutions described. How to couple these improvements into the TCWF algorithm is currently an area of active research at Lincoln Laboratory, and further testing is planned at the four ITWS prototype sites in the summer of 2001.

APPENDIX A
TRACKER PARAMETERS

TABLE A-1

Correlation box Size	28 km x 28 km
Use histogram for tracking levels: Number of levels Percentiles (%)	 6 (60, 70, 80, 90, 95, 99)
Minimum correlation for valid vector	.55
Temporal weighting of previous vectors: Global Local	 .25 .70
Min/Max valid weather in correlation box (%)	10/90
Speed limit (largest allowed vector)	120 km/hr
Global constraint	+/- 70 degrees in direction

APPENDIX B
SCORING TECHNIQUES

For all scoring techniques, the same storm example is shown along with the count of truth pixels, forecast pixels, false alarms, misses, and hits. A "False Alarm" (red) occurs when weather is forecast that does not occur. A "Miss" (blue) is assigned when the algorithm does not forecast weather that does occur and a "Hit" (green) is given for correctly forecast pixels. Some other statistics that are shown are the Critical Success Index (CSI) score and the "Bias". The CSI is a ratio of the number of hits to the number of hits, misses, and false alarms. The "Bias" is the ratio of the forecast pixels to the truth pixels. The different scoring techniques are discussed below.

Binary Scoring Technique

Binary scoring is a very straightforward scoring technique. It calculates the score by doing a pixel by pixel comparison between two images (i.e. Truth and Forecast images). If the two pixels being compared match exactly, a Hit is recorded for that pixel. If the pixels do not match, either a False Alarm (Forecast > Truth) or a Miss (Forecast < Truth) is recorded (See Figure B-1).

RED – FALSE ALARM
Forecast of ≥ Level 3
and Truth < Level 3

RED Striped – Not Scored
Forecast of Level 2 and
Truth < Level 3

BLUE – MISS
Forecast < Level 3 and
Truth ≥ Level 3

GREEN – HIT
Forecast and Truth
≥ Level 3

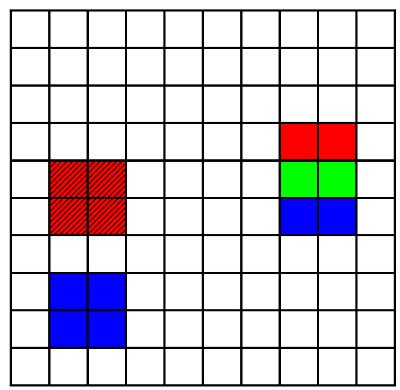


Figure B-1: Example of Binary Scoring

Number of Truth Pixels = 8
Number of Forecast Pixels > Level 3 = 4

Number of False Alarms = 2
Number of Misses = 6
Number of Hits = 2

$$CSI = \frac{\text{HITS}}{\text{Hits + False Alarms + Miss}}$$

CSI = 20 %

$$\text{Bias} = \frac{\text{\# Forecast Pixels}}{\text{\# Truth Pixels}}$$

Bias = 0.5

Box Scoring Technique

Discussions with potential users of the Terminal Convective Weather Forecast (TCWF) produced a set of guidelines for the forecast accuracy. Users desired a forecast that was accurate to within 5nm (10 KM) and 10 minutes of the actual weather. The Box scoring technique was developed to score the forecast using these guidelines. If a truth pixel ≥ Level 3 does not verify with a forecast pixel that is greater than Level 3, a 19-pixel by 19-pixel (1-km resolution pixels) is centered on the truth pixel. If there are any Level 3 forecast pixels located in the grid, we count the forecast as a hit (see Figure B-2). After all of the unverified truth pixels have been examined and scored, the remaining forecast pixels are examined. The following example is using a 5-pixel by 5-pixel (4-km resolution pixels) grid. In real-time operations, TCWF uses 19-pixel by 19-pixel (1-km resolution pixels) grid for the Box score.

RED – FALSE ALARM Forecast of ≥ Level 3 and Truth < Level 3

RED Striped – Not Scored Forecast of Level 2 and Truth < Level 3

BLUE – MISS Forecast < Level 3 and Truth ≥ Level 3

GREEN – HIT Forecast and Truth

≥ Level 3

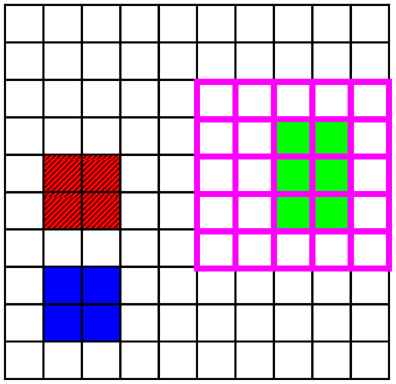


Figure B-2: Example of Box Scoring. 5x5 grid is centered on a pixel. The search of the 5x5 grid finds 2 forecast pixels. Therefore, the forecast is scored as a hit.

Number of Truth Pixels = 8

Number of Forecast Pixels >

Level 3 = 4

Number of False Alarms = 0

Number of Misses = 4

Number of Hits = 6

HITS

User Scoring Technique

Users from the 1998 TCWF Dallas-Ft. Worth demonstration reported that the TCWF algorithm was performing better than the reported forecast accuracy scores indicated. There were also concerns that users would misinterpret the results. Some users reported that they felt a CSI of 50% was no better than “a flip of a coin” (probably interpreting the CSI as a Probability of Detection (POD). The equivalent CSI for a “flip of a coin” forecast would be approximately 33%; thus a CSI of 50% shows incredible skill. The User Scoring technique was designed to deal with these issues. This technique is an enhancement to the Box technique described above. For the User Scoring, a grid is positioned over a ≥ Level 3 truth pixel that does not verify directly with a ≥Level 3 forecast. First, a search of this grid for a ≥Level 3 forecast is conducted. If a ≥ Level 3 forecast is found, a hit is recorded. If no ≥ Level 3 forecasts are found, the grid is searched again for any Level 2 forecasts. If a Level 2 forecast is found, a partial hit and a partial miss are recorded (See Figure B-3). After all of the truth pixels have been examined, any remaining forecast pixels will be examined. If a ≥ Level 3 forecast verifies with a Level 2 truth, then a partial hit and a partial false alarm are recorded. The partial credit penalty percentage is parameterized; we have selected 0.25 hit and 0.75 miss/false alarm. The following example is using a 5-pixel by 5-pixel grid. In real-time operations, TCWF uses 19-pixel by 19-pixel grid for the User score.

RED – FALSE ALARM
Forecast of ≥ Level 3 and Truth < Level 3

RED Striped – Not Scored
Forecast of Level 2 and Truth > Level 3

BLUE – MISS
Forecast below Level 3 and Truth ≥ Level 3

GREEN – HIT
Forecast and Truth of ≥ Level 3

GREEN Striped – PARTIAL HIT/PARTIAL MISS
Forecast of Level 2 and Truth of ≥ Level 3

Actual Weather **Actual and Forecasted Weather**

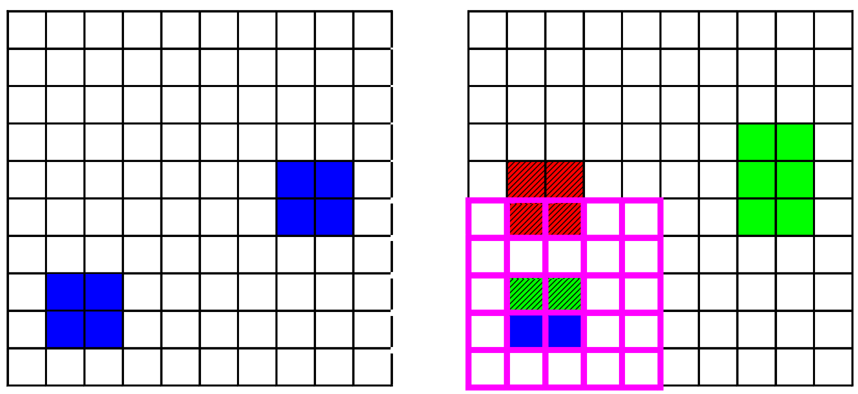


Figure B-3: Example of User Scoring. 5x5 Grid is centered on the Level 3 Truth. There are no Level 3 forecasts in the 5x5 box, but there are Level 2 forecasts. Therefore, the forecast is scored as a Partial HIT (0.25)/Partial MISS (0.75)

Number of Truth Pixels = 8
Number of Forecast Pixels > Level 3 = 4

Number of False Alarms = 0
Number of Misses = 3.5
Number of Hits = 6.5

$$CSI = \frac{HITS}{Hits+False\ Alarms+Miss}$$

CSI = 65 %

$$Bias = \frac{\#\ Forecast\ Pixels}{\#\ Truth\ Pixels}$$

Bias = 0.5

APPENDIX C
TCWF OPERATIONALLY SIGNIFICANT DAYS MEM-2000

TABLE C-1

SITE	DATE	TIME (UT)	SYNOPSIS
MEM	25-Mar-00	1518-0110	An approaching weak cold front brought convection to the area. Initial convection was isolated, but a well-organized arc of storms rapidly formed along a convergence boundary that tracked eastward toward the airport. *TCWF: This was a good day for TCWF with both the timing and the motion accurately depicted. Scores began at 70% for 30 minutes and 45% for 60 minutes. As the convection became well-organized the scores were 90% accurate for 30 minutes and 80% for 60 minutes. Scores remained high for several hours until the convection began to dissipate. The CWSU meteorologist used TCWF during the afternoon briefing while the TRACON supervisor used the product to route a plane from MEM to Jackson, Miss.*
MEM	26-Mar-00	2227-0827	Activity began to the west along two approaching cold fronts. Eventually light to moderate precipitation reached the TRACON. *TCWF: Overall the TCWF scores remained fairly high throughout the mission with the scores only dropping as the convective activity began to decay and disorganize. Scores ranged from 40-95% for 30 minutes and 30-85% for 60 minutes.*
MEM	29-Mar-00	2223-0623	A trough moved into the area bringing with it heavy precipitation. Isolated showers developed ahead of the more organized cells. *TCWF: Scores were produced only twice during the mission due to the pixel threshold requirement. Although scores were scares, TCWF did seem to accurately predict cell motion and was useful in determining which gates would be impacted and when they would clear.*
MEM	1- Apr-00	2133-0953	An approaching frontal system and moisture from the Gulf provided the necessary ingredients for widespread convection. Much of the convection was embedded and the stronger cells remained south of the TRACON. Moderate precipitation was recorded at the airport. *TCWF: The algorithm did a good job considering the fact that the convection was embedded and, thus, somewhat disorganized. Initially, the 200nm product scores were 75/60% for 30 and 60 minutes, respectively, and climbed to 85/65%. Initial TRACON scores were 75/60%, but dropped with the lack of organized convection. The 30-minute product accurately forecast the onset of level 2 precipitation on the runways. The TMU used TCWF to determine which of the southern airways would be impacted by convection.*

SITE	DATE	TIME (UT)	SYNOPSIS
MEM	2-Apr-00	1148-0333	A stationary front provided the impetus for widespread embedded thunderstorms. The convection primarily impacted the gates and the airport recorded moderate rainfall. *TCWF: The first 200nm TCWF scores were 70% and 35% for the 30 and 60 minute forecasts, respectively. These scores ranged from 45-80% for 30 minutes and 35-65% for 60 minutes. TRACON scores were not produced due to the sparse number of pixels.*
MEM	3-Apr-00	0851-1957	A large area of stratiform rain with embedded areas of convection overspread the TRACON. A few lines of heavy showers impacted the airport, followed by a few hours of lighter precipitation. *TCWF: Scores were posted for only a portion of the mission due to the lack of level 3 at the beginning and end of the event. Initial scores were low due to the disorganized nature of the showers, but climbed as the lines of heavier precipitation formed. TRACON scores ranged from 50-65% for 30 min and 30-40% at 60 minutes. 200nm scores ranged from 60-85% for 30 minutes and 55-70% for 60 minutes.*
MEM	7-Apr-00	1618-0555	An approaching cold front along with a moist and unstable southerly flow sparked strong thunderstorms across the sea. The initial thunderstorms developed along a warm front into a WSW/ENE line (with up to level 6 cells) that affected the northern airways. The strongest cell (west of the airport) formed into a bow echo and produced golf-ball size hail. As the squall line approached the airport, the intensity weakened. *TCWF: The TCWF product generated moderate-high forecast scores throughout the mission. The initial scores for the 200nm product were 70/20% at 30 and 60 minutes. These scores rose quickly and peaked at 95/80%. Scores for the TRACON product were also moderate-high (i.e., 70-90% for 30 minutes and 65-80% for 60 minutes). TCF predicted the arrival of the storms at the airport to within 5 minutes on the 30-minute forecast and within 10 minutes on the 60-minute forecasts. NWA used ITWS/TCWF for weather briefings and to determine gaps in case their planes were caught on the east side of the line. The TMU used the forecast product to determine the timing of the airport impact and plan the arrival push accordingly.*
MEM	16-Apr-00	1521-0855	Isolated showers organized into a broken line of echoes that tracked through the northern gates. Stronger cells also developed to the SW and tracked north and south of the airport. The airport reported a maximum of level 3 precipitation. *TCWF: TRACON scores were not produced due to lack of level 3+ pixels. The 200nm product scores peaked at 85% and 65% and remained relatively high for most of the mission. The TMU used ITWS/TCWF to determine how long the airways/jetways would be impacted by strong convection.*

SITE	DATE	TIME (UT)	SYNOPSIS
MEM	20-Apr-00	1348-2248	Light showers developed near the airport. Most of the scattered precipitation, along with a broken line of echoes, was located outside the TRACON. *TCWF: No scores produced due to sparse number of level 3+ pixels.*
MEM	23-Apr-00	1650-1050	An approaching low-pressure system brought scattered light showers during the morning and heavy rain during the late afternoon and evening. An impressive line of level 3-5 convection passed through the northern half of the TRACON in the evening hours, coincident with a second line of level 4 storms that affected the airport. *TCWF: Did a very good job handling the variable motion of the precipitation. Initial 200nm scores were low but quickly climbed as the convection became more organized. Thirty minute scores peaked at 90%, while 60 minute scores peaked at 70%. Initial TRACON scores were 70/60%. As the convection became more organized, scores once again climbed. Airport convective impacts were highly accurate even on the 60-minute forecast.*
MEM	27-Apr-00	1752-0441	A line of thunderstorms that built south along an approaching cold front characterized this mission. The line, initially broken in nature, filled in as it moved south through the TRACON, affecting the airport and virtually all arrival and departure gates. *TCWF: Initial scores at 200nm were 40/30%, while the TRACON came in at 60/30%. It appeared that the high growth rate of the cells might have been responsible for the initially low scores. The TRACON scores gradually climbed to 70/45%. The algorithm's 200nm scores ranged from 40-75% (30 minute) and 20-60% (60 minute). TCWF was used in planning and collaborative decision making.* NOTE: At 2240, site personnel noticed a splinter-like feature along an E/W-orientated convergence feature on the 60 minute forecast product. The TCWF error corrected itself on the following update. An optimization study was done to correct this problem.
MEM	1-May-00	1942-0242	A short wave was responsible for convective development to the W/NW. This activity intensified to level 4/5 and impacted the airport. The storms then organized into two distinct lines associated with outflow boundaries and moved through the eastern gates before decaying. *TCWF: Storm growth and decay played havoc with the algorithm during the early stages of the mission, which reduced the forecast scores and caused the airport impact timing to be incorrect. Once the convection became organized, the scores remained high until the weather decayed late in the mission. The initial 200nm scores were 0/10% and peaked at 95/65%. The first TRACON scores were 65/35% and remained fairly consistent while the echoes impacted the TRACON. ITWS/TCWF products were used primarily for traffic re-routing, gate load balancing, and runway arrival rate/usage planning. There were no major delays and no diversions, which can be partially attributed to the ITWS/TCWF products* .

SITE	DATE	TIME (UT)	SYNOPSIS
MEM	2-May-00	1808-1900	A low-pressure system located over NW AR brought copious amounts of moisture into the area and produced scattered thunderstorms to the SW of the TRACON, which progressed slowly NNE. During the evening, the convection organized into a NW/SE line and crossed the airport with heavy precipitation. The impact lasted for about two hours and affected the NWA evening push. The line continued its NE trek through the northern gates and exited the TRACON, as another line of storms developed to the SW and affected the SE arrival gate and eastern airways. The mission continued as the next wave of thunderstorms approached from the SW (see May 3rd). *TCWF: Performed well on this mission. Initial 200nm scores were 80/45% for the 30 and 60 minute forecasts, respectively. These scores peaked at 90/75% during the evening when the line became organized and crossed the airport. TRACON scores were first produced about 1.5 hours after the 200nm scores, starting at 65/40% and remaining near 75/60% while the line passed through the TRACON. TCWF was primarily used to determine the precipitation impact timing at the airport and gates.*
MEM	3-May-00	0900-2000	The pattern from the previous mission continued as waves of activity moved up from the south, but decayed upon entering the TRACON. Finally, a batch of showers managed to hold together as it traversed the airspace, providing the airport with an extended period of light-moderate (level 1-3) precipitation. Stronger convection impacted the gates. *TCWF: TCWF produced moderate to high scores depending on the organization of the convection. The 200nm forecast numbers were initially high (80/60%), but dropped to 60/35% before rebounding slightly towards the end of the mission. The initial TRACON scores were 50/50% and rose slowly over the course of the mission. This was a good case for storm growth and decay.*
MEM	4-May-00	0032-1502	Initial activity entered the SE gate from the south and strengthened as it tracked northward. While the brunt of the convection missed the airport to the west, a level 4/5 cell did cross the ARENAs. In addition, another area of thunderstorms was headed for the airport from the SSW. These cells combined with the earlier storms to produce a train of convection along the extended approaches. *TCWF: The TCWF product did an excellent job once the convection became organized. The initial 200nm scores (75/50%) were produced at 0205, with the initial TRACON scores (65/50%) evident 1.5 hrs later. These scores climbed steadily as the convection became more organized and peaked at 95/85% and 85/75% for the TRACON and 200nm products, respectively. The scores remained high until the convection began to decay and become disorganized. Airport impact timing was off by only about 5 minutes on the 30-minute forecast. TCWF was used to determine which gates would be impacted and to proactively route traffic to alternate gates.* Mission II on the 4th began as isolated level 4/5 cells developed in the northern gates. Cell motion was N at 20-30 knots. By evening, the isolated cells were decaying, but an area of strong thunderstorms was moving into the

SITE	DATE	TIME (UT)	SYNOPSIS
		1800 (4th) - 2020 (5th)	southern gates. As these thunderstorms tracked north out of the TRACON, scattered level 1-3 showers broke out in the eastern gates. Overnight, two areas of rain, one with embedded level 4/5 storms, moved into the TRACON from the south. The second area of weather moved east of the airport while a batch of showers skirted the western gates. During the afternoon of the 5th, a broken line formed and moved slowly NE through the eastern gates. *TCWF: Scores varied during this long mission. 200nm scores started off moderately low, but climbed as the line of storms moved through the western gates in the evening. They peaked at 80/75% before the amount of level 3 decreased significantly. TRACON scores (80/70%) were only posted for a brief time on the 4th. No scores were posted overnight due to a lack of level 3. When 200nm scores reappeared with the morning activity, they remained high, peaking at 95/90%, before storm growth and decay knocked the 60 minute scores down substantially. TRACON scores also reappeared in the morning and peaked at 85/80%. TRACON scores dropped in tandem with the 200nm scores on the 5th. During periods of significant convective activity, TCWF was used to determine which areas of the airspace would be impacted over the next 30-60 minutes.*
MEM	5-May-00	2025-1155	The system was restarted as scattered showers continued to track northward through the TRACON. Scattered showers briefly impacted various gates during the first part of the mission. A few of these interspersed cells brought light to moderate precipitation to the airport. Eventually, the individualized nature of the storm cell activity gave way to a largely benign stratiform precipitation shield. *TCWF: The TCWF's TRACON and 200nm products garnered fairly respectable scores. After an appropriate amount of level 3 pixels became available within the TRACON, the 30/60 minute scores gradually climbed from 50/30% to 90/85%. 200nm scores were generated throughout the entirety of the mission, peaking at 85/75%.*
MEM	9-May-00	1854-0607	Thunderstorms formed to the west along an approaching cold front. While the cells tracked ENE/45 knots, the entire envelope moved at a slower pace to the ESE. The squall line/outflow moved into the western portion of the TRACON as storms developed along the SW flank. There was also some growth ahead of the line in the northern gates, but these cells tracked quickly away from the airport. A batch of cells tracked over the airport, bringing primarily light-moderate rainfall. After impacting the airport, the line became somewhat disorganized with embedded convection being the rule. *TCWF: The TCWF product was highly accurate for this event. In particular, the forecast product was very good at portraying which cells would impact the runways and which ones would only impact the approach/departure corridors. The 200nm scores initialized at 90/65% and peaked at 90/80%. Scores remained high throughout the mission. The first TRACON scores were 85/70% and remained moderate-high until the convection became more isolated in nature. Scores rebounded during the latter stages of the mission. Users were interviewed after the mission and were extremely pleased with*

SITE	DATE	TIME (UT)	SYNOPSIS
			level 1-2 prior to impacting the airport. Convection then tracked into the SW gate only to decay before reaching the runway complex. This pattern persisted until the end of the mission. *TCWF: During the period of organized convection, the scores were high, but dropped later in the mission, as the convection became more isolated. The scores were also compromised somewhat by storm growth and decay. Even so, the forecast product did a great job of showing that the strongest convection would not impact the TRACON or airport. 200nm scores peaked at 90/70% and then declined steadily. Initial TRACON scores of 95/85% were generated as the 200nm scores climbed back to 85/70%. Within an hour, there was no longer enough level 3 weather to produce TRACON scores. The 200nm scores remained moderate-high until weather moved out of the area.*
MEM	22-May-00	2052-0638	As thunderstorms tracked in from the W, they diminished significantly in intensity after encountering a more stable environment. The mission began with the formation of light to moderate thundershowers located ~30nm SSE of the airport. Within an hour, convective activity within the TRACON was in various states of decay and the strongest shower activity was located to the north of MEM. New cell growth occurred behind the decaying cell complex over the western airways. By 2315, these fast-growing cells had reached heights of 48kft and were tracking east @ 20-25 knots. But within half an hour, this second cluster of cells had also weakened significantly. Over the next couple of hours, it and associated weaker showers tracked ESE through the NW gate and across the TRACON. *TCWF: The first 200nm scores came in at 20/15%, and ranged up to 50/35% during the mission. Due to the lack of an appropriate amount of level 3 and greater pixels, TRACON scores were never generated.*
MEM	23-May-00	1246-2116	Initial convection developed in the NW/NE quadrants just inside the TRACON boundary. The cell motion was ESE @ 25-35 knots, with the strongest storms located outside the airspace to the N. These cells developed rapidly in intensity and areal coverage and began impacting the entrance to the NE arrival gate. As the storm complex tracked through the eastern gates, new growth was evident on the western flank. Within an hour, the main area of convection was diminishing in intensity and areal coverage. During the late morning/early afternoon hours, isolated thunderstorms (level 2-4) developed as the wind shifted back to SSW. Several weak cells crossed the airport bringing light to moderate precipitation. *TCWF: The forecast product did a good job showing that the complex would miss the airport and only impact the gates. The scores were probably degraded somewhat by the rapid cell growth. The initial 30-minute scores for both products (75 and 80%) were produced at 1335. 60-minute scores were produced one-half hour later. The 200nm score peaked at 80/60%, while the maximum TRACON score was 80/75%. During the departure push, several of the N gates were closed with the aid of ITWS/TCWF products and traffic was rerouted pro-actively through the E, S, and W gates. The products were also beneficial in showing which airways to avoid due to convection.*

SITE	DATE	TIME (UT)	SYNOPSIS
MEM	25-May-00	02-15-0920 0924-1936	A cold front instigated convection across the northern gates and airways/jetways. As the storm complex tracked eastward, a weak shower formed on the southern end and crossed the field. *TCWF: The forecast scores for this weather event were high due to the highly organized nature of the storms. They peaked at 85/70% and 90/70% for the 200nm and TRACON products, respectively. ATC personnel remarked that TCWF was useful in helping to alleviate the guesswork of how much impact the storms would have.* An approaching storm complex affected the western airways until 1100, when the remnants of the system began affecting the western TRACON. Only light to moderate showers existed along the northern and western gates, as most of the shower activity passed just north of the TRACON. After moving east of the TRACON, some storms began to re-develop outside the NE gate and a couple reached level 6 with indications of severe hail. These storms continued moving east and during the afternoon only a few short-lived showers (level 2/3) popped up along a boundary just south of the airport and in the eastern gates. *TCWF: The product did not issue any scores, but advection of the few level 3 cells seemed accurate.* NOTE: The only problem to note was with an "artifact" in the forecast product. Also, Investigation revealed that the scoring software was not running on this day.
MEM	26-May-00	0900-1540 1849-0129	A warm front brought a line of thunderstorms to the area during the early morning hours. There was a significant gap noted in the line over the SW arrival fix. The entire line continued moving north and impacted virtually all of the E/W/N gates over time. As the line was on the northern fringes of the TRACON, there was new growth within the gap, completely filling in by the time the storms reached the northern portion of the airspace. *TCWF: This product generated moderate-high scores due to the organized nature of the convection and clearly showed the airport would remain precipitation free. The initial 30-minute scores of 70 and 85% for the TRACON and 200nm, respectively, were produced. Thirty minutes later, 60-minute scores were posted at 50 and 70%. The TRACON scores generally ranged between 30 and 70%, while the 200nm product had reported accuracies of 60-85%.* A few hours after the previous mission, severe thunderstorms quickly developed NW of the TRACON along a cold front. The line of thunderstorms entered the TRACON at 2012 and proceeded to track across the W, NW, N, and NE gates, finally exiting the TRACON at 2240. *TCWF: The algorithm began issuing scores fairly quickly and produced respectably high scores early on. TRACON and 200nm scores peaked at 85/70% and 90/70%, respectively. TCWF's 200nm product was also very persistent with tracking the line.*

SITE	DATE	TIME (UT)	SYNOPSIS
MEM	27-May-00	1108-0608	A continued unsettled environment led to the early formation of a squall line that approached the airport from the west. The line decayed after the system was started and most of the line tracked just north of the airport. Level 2 rain fell on the field. For the remainder of the morning, thunderstorms impacted the N/NW airways outside the TRACON. By 1630, the storms to the NW began organizing into a squall line that moved slowly east as cells trained NE along the line. The squall line reached the TRACON boundary by 1800 and impacted the western and northern gates for the next two hours. The majority of the squall line missed the airport to the north, though a few renegade showers on the southern end managed to drop moderate rain around 2000. The squall line decayed significantly as it crossed the eastern gates, but new storms grew on the outflow boundary now located over the southern gates. These storms quickly developed to level 5 as they moved across the SE gates. At the same time, a large rain shield was moving into the TRACON from the west. This rain moved slowly east and the airport received light to moderate showers for well over an hour. By 0300, a large area of rain had tracked into the south gates from the west just ahead of the cold front. *TCWF: Scores varied as the weather became more organized and then decayed during the morning and early afternoon. The NEXRAD outage sealed its fate by mid-afternoon. Scores reached as high as 80/70% (TRACON) and 90/75% (200nm) by late morning when the convection was organized. Scores then dropped (esp. TRACON) as decay took place and were at 40/35% (TRACON) and 75/60% (200nm) when the NEXRAD went down. TCWF was useful in determining when the gates and airways would be impacted and for how long. This allowed ATC and the ARTCC to proactively route aircraft towards or away from affected gates.*
MEM	13-Jun-00	2202-0238	The system was brought up as isolated thunderstorms developed SSW of the airport. A few short-lived and widely scattered thunderstorms tracked slowly through the TRACON, mainly affecting the SE and SW gates. Thunderstorm decay rapidly accelerated after local sunset. *TCWF: The algorithm began generating scores about 1 1/2 hours after system start up. Only 200nm scores were issued, peaking at 55/25%. No TRACON-based scores were noted; however, this was to be expected with the lack of level 3 precipitation in the area.*
MEM	14-Jun-00	1557-1457 (15^{th})	An influx of warm, moist, and unstable air ahead of a slow-moving cold front brought isolated to scattered convection to the Mid-South region. The initial activity during the morning/afternoon hours was driven by diurnal heating and was isolated in nature. By early evening as the front approached the area, the convection became stronger and more organized. Since the front stalled out, there was a significant time period with "training" echoes across the airport. *TCWF: Had an extensive workout throughout the mission and did a good job depicting the envelope motion, which varied from ENE-NNE. The initial 200nm scores were 60/25%. These scores begin to climb very quickly due to the organized convection to the NW. By 2147, they had reached 70/65%.*

SITE	DATE	TIME (UT)	SYNOPSIS
			TRACON scores were initially posted at 60/35%. The scores then remained high over most of the mission peaking at 90/85% (200nm) and 90/75% (TRACON). The main benefits to ATC were planning gate reconfigurations due to convection blocking many of the transition areas and determining hold locations.
MEM	15-Jun-00	1657-0412	Diurnal heating combined with an unstable atmosphere to spark scattered showers over the Mid-South. The initial activity was located 10-15nm W of the airport, although most of the cells were confined to the eastern half of the TRACON and Memphis Air Route Traffic Control Center (ZME) airspace. By late afternoon, most of the activity had moved east of the TRACON. Through the evening hours, the northern gates and airways experienced scattered showers until sunset, when activity waned. *TCWF: TCWF only produced scores at the 200nm range. These were posted for only a couple of hours and averaged 50/35%.*
MEM	16-Jun-00	1720-0235	The Mid-South was again between systems with scattered showers and thunderstorms developing by late morning and continuing through the evening hours due to diurnal heating. Initial activity was located over the south and east gates. After these showers decayed, the TRACON remained clear for a couple of hours. A few other showers and thunderstorms managed to pop up in the western TRACON during the day, but all cells decayed considerably with the loss of heating. A large area of thunderstorms located over 100nm to the N/NW (along a stalled cold front) continued through the night, but with NE motion did not affect the TRACON. *TCWF: Did a good job in the 30 minute time period, but scores were low at 60 minutes due to storm growth and decay. TRACON scores were only posted for a very short period and were moderate. 200nm scores started at 70/50% and peaked at 85/55% before falling the remainder of the mission. TCWF accurately depicted that the brunt of the activity would miss the airport, which dispatchers passed on to wary NWA flight crews.*
MEM	17-Jun-00	1428-0254	The system was brought up as light showers tracked over the airport in association with a cold front. Showers and thunderstorms developed throughout the TRACON for most of the mission, affecting nearly all of the gates. For the most part, the strongest convection remained away from the airport and the nearest that any significant precipitation came to the airport was at 1653, as level 5 tracked within 10nm to the south. Thunderstorm decay rapidly accelerated well prior to local sunset as a stratiform precipitation shield tracked into the area. *TCWF: Early on, the algorithm began producing respectably high scores. Both TRACON and 200nm scores were issued, peaking at 80/55% and 85/65%, respectively. Due to decaying weather, the associated TRACON scores dropped at about 2000.*
MEM	18-Jun-00	1242-0212	An approaching low-pressure trough and cold front combined to produce isolated to scattered convection. The initial activity (weak showers) developed just SW of the airport. During the morning hours, there were

SITE	DATE	TIME (UT)	SYNOPSIS
			several batches of showers that developed to the SW, but diminished in intensity prior to impacting the airport. The strongest activity was located outside the airspace. Another broken line of thundershowers had formed just outside the NW/N gates during this time frame along the slow-moving front. This was a classic case of decay in the NE sections and minor growth along the SW flank. As the front approached the airport, a few showers popped up within 10nm to the NE/NW. The showers continued to decay until 0210 when the only convection was located outside the TRACON to the east and south. *TCWF: 200nm scores ranged from 65-80% and 40-60% for the 30 and 60 minute scores, respectively. There were never any TRACON scores posted due to the small number of level 3+ pixels. The products were used to reconfigure gates and route aircraft through gaps in the most intense convection*.
MEM	19-Jun-00	1549-0424	A stationary frontal boundary draped across the region, combined with diurnal heating to produce isolated to organized convection. Most of the other activity within the airspace was weak and isolated. By 1830, there were two distinct clusters of convection located in the NW quadrant, which impacted most of the northern gates. There was also a batch of thundershowers located to the east, primarily outside the TRACON at this time. At 2338, there were a couple of cells that developed within 7nm to the NE and NW without any fanfare. *TCWF: Since the convection was not well organized, the forecast accuracies were lower than usual. The initial, as well as peak, 200nm scores were 60/35%. There was never any TRACON accuracy numbers due to the lack of weather pixels above the threshold. TCWF clearly showed that the airport would not be impacted.*
MEM	20-Jun-00	1802-0132	Isolated diurnally-driven showers and thunderstorms developed by early afternoon. Only a couple of cells actually formed within the TRACON and these were small and insignificant. The large majority of the cells that developed were located south and east of the TRACON where deeper moisture was present. All activity dissipated or moved well east by early evening. *TCWF: TCWF scores remained low at 200nm (and were never posted at the TRACON-scale) due to growth/decay and little movement.*
MEM	21-Jun-00	0832-0132	A well-defined synoptically induced line of thunderstorms tracked through NE AR, affecting the northern jetways/airways before losing organization after entering the TRACON. As the broken line moved south, a well-defined outflow boundary preceded it. The airport received moderate to heavy rain as cells tracked ENE along the line. The line of cells that trained over the airport began to decay from the west and the airport was precipitation-free by mid-morning. After a couple of hours of benign weather, another rain shield tracked across Arkansas and reached the airport by mid-afternoon. The heavier rain (level 2/3) stayed over the western gates while the eastern edges of the rain shield decayed over the eastern TRACON. In the meantime,

SITE	DATE	TIME (UT)	SYNOPSIS
			thunderstorms re-fired along an outflow boundary south of the TRACON. *TCWF: 200nm scores were the only ones posted during the mission. They started off at 70/35% and rose to 75/50%, then leveled off at 65/50%. Scores dropped out as the thunderstorms decayed. Scores re-appeared by mid-afternoon at 55/20% and quickly rose as storms to the south became more organized. They peaked at 90/75%. Delays were fairly extensive during the morning NWA push. However, NWA stated that TCWF was extremely useful in saving 2-4 diversions as the product showed that the convection would clear soon enough to allow the aircraft to continue to hold. The forecast, out to about 40 minutes, was used extensively by the NWA dispatcher.*
MEM	26-Jun-00	1609-1349	Convection on this day was the result of both diurnal/boundary and synoptic forcing. The initial activity developed along several local boundaries. Later in the afternoon and evening, a cold front provided the focal point for convection. While there were numerous strong thunderstorms, minimal upper-level support precluded any severe weather. The airport experienced several bouts of heavy precipitation. The TRACON remained relatively precipitation-free until 0330 when a cluster of showers formed in and near the SW arrival gate. This activity had more of a NE component and thus headed straight for the airport. There was rapid cell growth noted along the outflow boundary on the northern periphery, which allowed the cells to impact the runways earlier than forecasted. Weaker shower activity continued to train across the airport until 0735. After this, the stronger showers were generally confined to the S, with the runways only experiencing light precipitation. *TCWF: Initially, scores were low, but began to climb steadily by 1900. Up until the first system outage, the 200nm scores ranged between 70-80 and 35-55% for the 30 and 60-minute forecasts. The TRACON numbers were generally lower than this over the same time period. Once the product became operational again, the scores were also moderate to high, peaking at 90% for the 30-minute and 70% for the 60-minute product. The airport impact timing was degraded by cell growth at times, especially during the late evening round of storms. Other than this, the algorithm had a good handle on the track of the weather echoes and accurately showed when each batch would clear the ARENAs. The weather episode impacted primarily two pushes, the late afternoon NWA and late evening FedEx. There was extensive airborne holding (> 1 hr) and 13 NWA airplanes had to divert to their alternates. The TMU specialist reported that ITWS/TCWF were used for gate balancing/closures and to determine where/when to release planes that were holding. When the airport shut down, there was little that could be done to minimize the number of diversions. During the FedEx push, the primary benefits were determining hold locations, gate reconfigurations, and load balancing.*
MEM	28-Jun-00	2032-0715	An upper-level disturbance that moved through the area behind a cold front brought widespread shower activity to the ZME airspace. Thunderstorms also fired along the frontal boundary south of the TRACON. The large area of level 2/3 showers experienced some decay and two distinct areas of rain were

SITE	DATE	TIME (UT)	SYNOPSIS
			the result. One crossed the northern gates, while another traversed the southern gates and airways. The airport was left in between and received only a couple of light showers. Scattered level 1-2 showers developed behind these rain areas affecting most of the TRACON. By 0245, cells had formed into an east-west line just south of the airport. The level 2-4 cells trained across the southern gates for over four hours. During this time, the rest of the shower activity over the TRACON decayed. *TCWF: Only produced scores at 200nm and did a good job. The line, which developed south of the airport, was well prognosticated by the system. Initial scores in the afternoon were 75/55% and climbed to 90/65%. They dropped somewhat with decay in the storms to the south. TCWF did a good job of depicting the locations that would be impacted by heavier rain.*
MEM	7-Jul-00	0229-0720	Thundershowers that were located north of the TRACON tracked SE, missing the TRACON to the north. The nearest that any significant precipitation came to the airport was a level 3 cell to the NE that tracked within 45nm. *TCWF: Scores were only moderate due to growth/decay and the relatively small number of level 3 and greater pixels. TCWF aided in depicting which jetways/airways would be impacted.*
MEM	12-Jul-00	1330-0256	The outflow boundary from a decaying MCC over AR and MO provided the initial spark for convection during the morning hours. A batch of thunderstorms formed just outside the TRACON to the NW with motion to ESE at 10-15 knots. This activity briefly impacted the northern gates before decaying. As the first in a series of boundaries tracked SE, there were a few rainshowers that popped up within 20nm of the airport, mainly located in and near the NW arrival gate. The last in this batch of outflows sparked isolated convection over and near the airport. *TCWF: The 200nm scores were initially moderate/low for the 30/60-minute product. These scores typically averaged about 70/45% over the course of the mission. The TRACON scores were similar, peaking at 80/55%. The only problem to report was that the initial forecast showed the weather tracking S, while in reality the motion was ESE.*
MEM	13-Jul-00	1845-0100	Diurnally driven convection, aided by a weak trough over the southern portion of the airspace, popped up primarily south of the TRACON. A few cells also developed north of the TRACON. The only cells to affect the TRACON grew to level 4/5 over the SW/SE gates. They moved slowly south and out of the TRACON. The cells to the north, meanwhile, spawned outflows that helped in the development of new convection that grazed the northern gates before decaying. *TCWF: Initial 200nm scores were about 80/45%. They remained near this level, peaking at 85/70%, throughout the mission. TRACON scores were only posted for a brief time - at 70/55%.* NOTE: The FedEx dispatchers were trained on ITWS/TCWF webpage on this day. The webpage was being used by the ATC Coordinator on duty to

SITE	DATE	TIME (UT)	SYNOPSIS
			monitor conditions.
MEM	15-Jul-00	1736-0301	Isolated convection in the airport area prompted system startup. The showers were all short-lived and most activity had diminished by 2000, with the exception of scattered thunderstorms that had gained momentum in the eastern airways. By 2245, a cluster of storms had advected into the NE gate and skirted the eastern edge of the TRACON, while the outflow from these storms caused additional growth in the eastern departure gates. Meanwhile, a level 5 cell approached the TRACON from the west, but decayed as it reached the TRACON boundary. The cells to the east decayed significantly after sunset. *TCWF: Scores were first posted for the 200nm range at 30/5% (30/60 minutes). Scores steadily rose to 65/40% within two hours. They peaked at 70/45% and stayed near 60/40% for the remainder of the mission. TRACON scores were only posted for about an hour, peaking at 55/20%, but were generally lower than that.*
MEM	17-Jul-00	1655-0247	A MCC tracked eastward across the northern airways. Within several hours, this convection was waning and new cells had grown along the outflow boundary closer to the TRACON. The initial TRACON cells formed along the northern periphery of the airspace and rapidly developed southward towards the runway complex. One cell intensified to level 5/6 and brought heavy precipitation to the airport. As the main outflow tracked southward, there was a short line of thunderstorms that developed in the SE quadrant. A few isolated cells impacted the SW quadrant as well. *TCWF: 200nm forecast scores were produced for about 4 hours. The scores ranged from 55-80% and 20-40% for the 30 and 60-minute forecasts, respectively. Initially, the product showed the airport would not be impacted. The algorithm quickly captured new cell growth and gave a 15 minutes heads-up to advancing echoes. The motion and timing estimates were good for this event.*
MEM	18-Jul-00	0902-1640	For the most part, the strongest convective weather activity remained well away from the area. However, thunderstorms embedded within light precipitation tracked slowly through the TRACON. *TCWF: Only 200nm scores were issued, peaking at 95/80%. As showers and thunderstorms decayed, scores diminished precipitously. As thunderstorms re-developed, scores shot back up, then gradually diminished to 25/20% in conjunction with decaying weather conditions.*
MEM	20-Jul-00	1157-2330	A storm complex that developed over the Plains early in the morning worked its way across AR and MO during the morning. By 1730, the squall line had reached the NW gate. As the line traversed the western gates, cells developed in the airport area along a weak outflow. The main line hit the airport at 1845 bringing heavy rain and gusty NW winds. The strongest storms, however, passed through the northern gates in association with a bow echo. The squall line continued across the eastern gates and exited the TRACON by mid-

SITE	DATE	TIME (UT)	SYNOPSIS
			afternoon. *TCWF: Excellent job! 200nm scores reflected this, as they were first posted at 95/80% and remained at 95/90% for the majority of the mission until the storms exited the region to the east. TRACON scores started off in the moderate range as the line moved in, but peaked at 90/75% around airport-impact. Even during the time scores were not posted, the forecast itself did a good job. A conversation with the NWA chief dispatcher on duty revealed that they relied heavily on the forecast provided by TCWF to plan airport impact timing. TCWF and their meteorologists disagreed a little on this timing, and the weather actually split the difference. Thus, they were planning on being able to have all departures out by the time the line arrived. There were no diversions, delays, or holds during the event.*
MEM	29-Jul-00	1415-0856	Isolated showers and later scattered thunderstorms developed across western TN. Showers and thunderstorms tracked through the TRACON for most of the mission, affecting all of the gates as well as the airport. Some of the strongest convection tracked directly over the airport, with the most intense precipitation lasting for nearly an hour. *TCWF: Early on, the algorithm's 200nm 60 minute scores ramped up to 85%. Both TRACON and 200nm scores were issued, peaking at 75/60% and 90/80%, respectively. Due to a dearth of level 3 and greater weather, associated TRACON scores weren't generated until about six hours into the mission. TCWF provided a fair amount of benefit. ATC stated that they were "given long warnings as to where the weather would be, allowing aircraft vectors to be made around arrival gates." NWA indicated that TCWF saved one diversion with the aid of ITWS/TCWF by advising the flight crew when the airport would re-open.*
MEM	30-Jul-00	1544-0520	A trough combined with daytime heating and boundary convergence to spark scattered convection across the Mid-South. The initial activity developed to the south and northwest of the TRACON and remained outside the TRACON for most of the afternoon. Most of the cells were slow-movers. The initial airport impact occurred at 1557. Throughout the afternoon, a few weak showers popped up in the TRACON but dissipated quickly. Just before sunset, a cell developed rapidly to level 5 and produced a ring outflow that sparked additional echoes, mainly along the eastbound front. *TCWF: TCWF did an admirable job considering the fact that the cells were slow-movers, with significant growth and decay. The first 200nm scores (65%/NA) were produced at 1900. Within an hour, the forecast accuracy for this product peaked at 80/55%. Between 2100 and 2300 there was not enough weather to produce any scores.* *Once the accuracies were generated again at 2310, the scores were somewhat low, i.e. 40/10%. The scores climbed steadily though as the convection organized and had reached 80/35%. The 200nm scores peaked at 90/75%. The TRACON scores were significantly lower (fewer level 3+ pixels) and were only produced for about an hour.*

SITE	DATE	TIME (UT)	SYNOPSIS
MEM	31-Jul-00	1645-0335	By late in the morning, convection was firing along an outflow boundary/trough that stalled in the extreme eastern and southern periphery of the airspace. The stronger activity formed outside the TRACON to the east. A cluster of showers and weak thunderstorms that developed in the SE quadrant generated several outflow boundaries that merged and tracked westward towards the airport. Throughout the afternoon, the highest concentration of convective activity was confined to the SE quadrant. By 2300, a cluster of cells stretched from SE to NE across the runway complex. The cells to the east merged and became the dominant weather feature for the next several hours. *TCWF: During the early stages, the TCWF product showed the cells having a more northerly component, while in reality they were tracking more easterly. The 200nm product produced scores between 1750 and 0030. The scores were generally moderate (65/40%) due to the unorganized nature of the convection. The peak scores were 75/45%. ITWS/TCWF products showed ATC that weather to the east would not impact the ARENAs.*
MEM	1-Aug-00	1643-0245	The remnants of a cold front/trough set off a few thunderstorms by late morning, which organized into a broken line within a few hours. The strongest storms, initially, developed in an east-west line just north of the airfield. These storms eventually grew southward and produced an outflow that tracked over the airport. New cell growth was evident throughout the TRACON by mid-afternoon. The most concentrated activity was along the trough axis. Elsewhere, scattered convection affected many of the gates as growth and decay took place throughout the afternoon along outflows from existing cells. *TCWF: TCWF did "as expected" for a summertime day in which storms increased in organization as the day progressed, then decreased in the evening. Initial scores at 200nm were posted at 35/10%. Scores steadily rose through the afternoon and peaked at 85/40%. TRACON scores started at 35/10% and peaked at 75/60% by 2000. TRACON scores dipped thereafter, while 200nm scores remained near 75/35% until about 0000. TCWF did a fine job during the day of showing the general eastward progression of the cells. It aided in determining the length of time that the airport would be affected, though growth and decay also occurred that was not captured by the product.*
MEM	3-Aug-00	1733-0933	The system was brought up as an isolated shower formed near the airport. The most serious convection remained well away from the airport and the nearest that any significant precipitation came to the airport were two level 4 cells that formed 4nm SE and SW. The strongest thunderstorms developed mainly along the periphery of the TRACON, affecting only the northern gates late in the mission. *TCWF: Early on, the amount of moderate precipitation in the area wasn't sufficient to produce any scores. However, by evening, the algorithm began*

SITE	DATE	TIME (UT)	SYNOPSIS
			producing respectably high 200nm scores, which peaked at 95/90% by the mission's end.
MEM	4-Aug-00	1425-0135	An outflow boundary from thunderstorms to the north served to initiate convection during the morning hours. Initially, storms that had developed overnight were located east of the TRACON, moving to the SE, and new development was taking place just north of the airspace. The strongest cells, however, were located in the NE and W gates during the afternoon. These cells produced hail, strong winds, and torrential rains over eastern parts of Memphis and just south of West Memphis, AR as they moved slowly SE. TC*WF: TCWF scores were only posted at 200nm with 30 minute scores remaining between 70-90% the entire mission, while 60 minute scores were highly variable. They reached 70% a couple of times, but were more apt to be in the 35-50% range due to growth and decay.* NOTE: TRACON scores were at not available (N/A) when 200nm scores were available. Further investigation revealed a bug in the scoring software.
MEM	10-Aug-00	1541-0636	An approaching frontal system was the catalyst for convective activity throughout the TRACON. The initial storms impacted primarily the gates as well as the eastern jetways/airways. A thunderstorm also formed along an outflow boundary just NW of the runways. *TCWF: 200nm scores were available for a good portion of the mission, while the TRACON scores were only posted for about 3 hours. Scores peaked at 80/60% on the TRACON product and 85/60% on the 200nm product. The envelope motion was well depicted by the product and airport impact timing was within just a couple of minutes of actuality. Benefits included providing the knowledge, particularly to NWA, of how long the airport would be impacted, thus saving as many as 14 diversions (aircraft that got caught behind a line of storms) that were low on "holding fuel."*
MEM	18-Aug-00	1248-0228	This was another day characterized by synoptically induced convection as a cold front tracked through the region. Most of the cells were weak and poorly organized, which minimized the impacts. The airport only experienced a few passing showers. *TCWF: No scores were produced due to a lack of level 3+ weather.*
MEM	22-Aug-00	1956-0116	On this day, the atmosphere was primed for diurnally induced convection aided by local convergent boundaries. The cells intensified rapidly and were scattered throughout all quadrants of the TRACON. Two moderate showers brought rainfall to the airport environs, while a ring outflow expanded across the runways and produced isolated convection in the SE/SW quadrants. *TCWF: In general, scores ranged from 60-75% at 30 minutes and 30-40% at 60 minutes. The tracker had a hard time initially picking up on the slow motion of the cells that were located near the ARENAs. Due to the cell's juxtaposition to the airport, this caused some confusion as to whether they would impact the field. It turned out that TCWF was correct in showing that the airport would remain clear. NWA used the product for situational*

SITE	DATE	TIME (UT)	SYNOPSIS
			awareness and to advise crews of the status of the cells located just off the field.
MEM	24-Aug-00	1330-2230	The system was brought up as a large area of precipitation and embedded thunderstorms formed 50-100nm NW-NE of the airport. The most serious convection remained well away from the airport and the nearest that any significant precipitation came to the airport were level 2-4 cells that formed 25-70nm NW to NE. Later, level 2-3 showers again formed over the northern departure gates. By late afternoon, thunderstorm decay brought the mission to a close. *TCWF: After recycling TCWF due to system problems, 200nm scores were generated and peaked at 90/60%. However, there were no TRACON scores generated due to the insufficient amount of level 3+ weather.*
MEM	25-Aug-00	1515-1921	An MCC formed north of the airspace during the early morning hours. A strong high-pressure ridge over the Mid-South deflected the storm complex to the east of the airspace. *TCWF: No scores were posted though the system was used to monitor the decaying weather over the northern airways.*
MEM	26-Aug-00	1837-0307	Another MCC approached the region from the north in the afternoon hours. This system decayed prior to entering the TRACON. *TCWF: Produced only 200nm scores, which peaked at 90/40%.*
MEM	10-Sep-00	1615-0615	Scattered convection occurred TRACON-wide on this mission. Cells to the SE developed along a local boundary feature and produced an outflow that tracked eastward away from the airport. By 1900, the convection had organized into a broken line along this feature. Isolated convection continued to plague the NE/SE quadrants and N/E jetways and airways throughout the afternoon hours. During the late afternoon hours, several additional batches of convection formed to the S and SW of the airspace outside 90nm. This activity tracked NNE, causing the storms to the SW to miss the TRACON, while the southern-most cell complex headed for the airport. The main cell complex continued its NNE trek, but never filled in completely and decayed during the evening. *TCWF: There were no scores posted until late afternoon due to the low number of level 3+ pixels within the coverage domain. The first 200nm scores were 50/20% and peaked at 95/75%. The initial TRACON scores were quite impressive (95/90%). The scores remained quite high until being dropped at 0343 (TRACON) and 0350 (200nm). A review of the pixel count revealed that the number had dropped just below the threshold for issuing scores. The optimum setting for this threshold is still being evaluated. The TCWF product did an excellent job tracking and indicating the rapid decay of the main storm complex. The TRACON and TMU air-traffic control specialists used ITWS/TCWF to route traffic to those gates that were not being impacted by convection.*

SITE	DATE	TIME (UT)	SYNOPSIS
MEM	11-Sep-00	1732-0123	The system was brought up as isolated showers and thunderstorms formed over portions of north central MS to the TN River. *TCWF: During the first hour of the mission, the algorithm's 200nm 60 minute scores ramped up to 65%. Both TRACON and 200nm scores were issued, peaking at 95/80% and 90/70%, respectively.*
MEM	12-Sep-00	1026-2330	A line of moderate to heavy showers and thunderstorms along a convergence area tracked into the Mid-South from the NW during the early morning hours. This line tracked through the TRACON during the first 3 1/2 hours of the mission, affecting all of the gates as well as the airport, exiting the TRACON's SE boundary by 1500. *TCWF: Early on, the algorithm's 30 minute scores ramped up to 85% (TRACON) and 80%(200nm). Later in the mission, TRACON and 200nm scores had impressively peaked at 95/85% and 90/85%. Due to a lack of level 3 and greater weather, all scores had significantly diminished by late afternoon. TCWF was useful in determining the exact timing of gate impacts.*
MEM	15-Sep-00	0043-0500	A strong cold front passed quickly through the area during the evening hours. With light south winds ahead of the front and gusty north winds behind, a decent convergence zone set up along the front, causing scattered thunderstorms to form in the late afternoon over SE MO and advect SE into the TRACON. The cold front continued to push the cells SE@25 knots as outflows from the cells helped to lengthen their lifespan. All precipitation activity missed the field. After passing by the airport, cells generally commenced a slow decaying trend and diminished by the time they reached the southern TRACON boundary. *TCWF: There were never enough pixels of significant weather within the TRACON or en-route airspace to generate any scores, though the motion of the isolated cells was tracked well.*
MEM	20-Sep-00	1717-0500	An approaching cold front and influx of moisture/instability, brought thunderstorms to the MEM area. Even with the strong winds, there were weak showers that had developed by late in the morning in the NE/SE quadrants. Stronger cells were also located to the south and east of the airspace by early afternoon. The initial activity briefly impacted the SE/E gates, as the motion was NE at 25 knots. By mid-afternoon, another batch of showers had formed along the Mississippi River to the SW. These cells intensified to level 6, but only impacted the S/SE gates. Over the next hour, the cells to the S intensified, while the fast-moving cold front approached from the NW. *TCWF: The TCWF product was accurate in indicating the convection near the airport would not play a major role in air traffic decisions. The 200nm scores peaked 85/65%. Most of the lower scores during the mission were associated with time periods of significant cell decay.*
MEM	23-Sep-00	1410-2140	Several factors, including a stalled cold front, combined to produce a convective system that moved across southern MO and northern AR during the early morning hours. New cell growth was evident ahead a boundary as a

SITE	DATE	TIME (UT)	SYNOPSIS
			line of showers and thunderstorms formed from ENE-WSW. The airport received only level 2 rainfall, though level 5 storms formed off the airport. As the new line of cells merged with the now-departing thunderstorm complex, an area of stratiform rain fell over the northern gates for a couple of hours. Isolated showers to level 4 intensity formed along an airport convergence boundary and the field again received a light shower. By late afternoon, these showers, the boundary, and other isolated showers that had formed, had dissipated. *TCWF: TCWF did a very good job of tracking the main area of thunderstorms. The first full set of scores posted at 1529 (TRACON - 80/65% and 200nm – 75/55%). They climbed from there, peaking at TRACON - 95/90% and 200nm - 85/70%. The 200nm scores remained high (i.e., 95/60%) as the storms moved east out of the TRACON and into the enroute airspace. The products were used primarily to route traffic around the most severely impacted transition areas.*
MEM	24-Sep-00	0641-0315	Another cold front moved through a warm/moist/unstable air mass across the Mid-South and provided the spark for widespread and long-lived convection. The initial storms had fired by the early morning hours across the northern gates and airways. These storms only impacted the northern extremities of the TRACON. Just after the first wave had cleared the airspace, isolated cells redeveloped in the same area (NW/NE quadrants) along an outflow boundary. By the time this activity cleared the TRACON, a large area of stratiform precipitation with embedded convection approached from the west. The leading edge had encroached into the TRACON by 1230. The cell motion was NNE/25-35 knots, while the line moved to the E/20. Eventually, the northern storms ejected a gust front that headed for the airport. A few cells developed on this boundary within 20nm, but raced quickly away from the runway complex. Shortly thereafter, the airport was experiencing light precipitation. A cell that had formed 18nm/SW hit the runways at 1512 and brought a brief period of moderate and heavy rainfall. This batch of precipitation also impacted the NE/E gates before decaying by 1700. *TCWF: The TCWF product did a great job of tracking this system and showed that the airport would not be impacted by any of the strong convection. The initial TRACON and 200nm scores (90%/NA and 95%/NA) were produced at 0730. The 200nm scores remained high throughout the mission, peaking at 95/90%. TRACON scores also remained high throughout the mission, peaking at 90/85% several times. Without a doubt, this was one of the most excellent scoring cases of the year. Even though the mission was long, the air traffic impacts were limited primarily to the morning NWA push. The main system benefits were shared situational awareness, providing deviation headings, and reconfiguring the arrival/departure gates. The TCWF product provided an added benefit by showing that the airport would escape the strongest convection.*

TABLE C-2
Memphis Daily Averages 2000

DATE	Duration (hours)		Total Truth		Forecast BIAS		Binary CSI Scoring		Box CSI Score (%)		User CSI Score (%)	
	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min
25-Mar-00	8.93	8.44	52963	53697	1.0339	1.2576	12.43	5.49	63.88	40.45	73.99	52.31
26-Mar-00	9.16	8.67	81817	82888	0.8957	1.0725	17.55	9.74	67.3	50.89	79.39	66.52
29-Mar-00	5.75	5.26	2356	3391	0.6566	0.9534	4.69	2.17	47.85	25.05	68.97	42.33
1-Apr-00	11.5	11.01	230479	225300	0.9494	1.04	16.23	8.26	58.76	38.16	73.04	55.02
2-Apr-00	14.96	14.46	116384	110064	1.0027	1.0679	10.56	5.05	42.58	23.78	60.13	43.46
3-Apr-00	9.31	9.81	73481	69868	0.9993	1.1241	5.73	2.95	39.01	22.2	59.55	43.23
7-Apr-00	12.69	12.17	299369	298842	1.0046	1.0276	32.48	19.17	80.6	65.07	87.07	75.38
11-Apr-00	10.5	10	1653	358	1.6981	6.5419	10.37	0.22	66.59	8.95	84.03	34.73
16-Apr-00	16.67	16.22	108881	108859	0.9241	0.8938	24.83	12.18	59.29	41.37	67.11	49.75
23-Apr-00	16.77	16.25	70968	72048	1.0087	1.0935	9.98	4.61	62.59	41.41	77.85	59.7
27-Apr-00	10.11	9.61	64228	66528	0.9667	0.9744	16.77	6.23	57.33	36.15	67.32	47.44
1-May-00	6.25	5.76	20040	20705	1.0701	1.1258	13.99	3.45	77.05	43.77	85.63	59.39
2-May-00	24.99	24.49	200408	203423	0.9756	1.0667	13.13	5.1	63.02	39.05	75.17	54.78
4-May-00	13.26	12.79	98128	98701	1.1184	1.2861	11.54	4.3	59.67	36.36	72.42	51.79
4-May-00	25.59	25.1	96928	96976	0.9503	0.9695	9.93	3.6	55.23	33.62	67.16	47.93
5-May-00	14.58	14.08	158540	155039	0.9614	1.1493	13.08	4.86	66.21	39.9	79.21	57.21

DATE	Duration (hours)		Total Truth		Forecast BIAS		Binary CSI Scoring		Box CSI Score (%)		User CSI Score (%)	
	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min
9-May-00	11.29	10.78	248571	248907	0.988	1.0084	26.51	13.26	71.86	50.2	80.66	62.84
13-May-00	6.19	5.67	410829	390734	0.9994	1.2526	24.38	13.25	70.48	48.94	79.13	61.08
18-May-00	17.17	16.68	230404	227645	1.0254	1.3487	21.46	10.38	61.6	36.44	73.97	52.38
22-May-00	8.96	8.46	13057	12858	0.728	0.8906	6.91	4.67	30.71	19.28	45.13	28.01
23-May-00	7.7	7.2	72675	61132	1.0924	1.5053	16.76	7.15	61.18	38.21	71.07	50.74
25-May-00	6.38	5.87	370825	362440	1.1232	1.3238	39.73	24.95	66.06	50.22	74.28	60.49
26-May-00	5.86	5.36	190112	183710	0.8943	0.8218	28.56	16.01	66.16	49.61	74.52	60.63
26-May-00	5.81	5.3	218287	192364	0.946	1.0772	32.39	21.58	72.25	57.67	79.52	67.05
27-May-00	7.98	7.46	205924	203438	1.0828	1.248	24.42	14.87	69.13	50.87	77.86	61.95
15-Jun-00	10.21	9.71	10224	11965	0.8607	0.9083	6.22	1.61	37.88	18.7	52.52	30.16
17-Jun-00	11.49	11	329006	320801	0.9451	1.0228	14.61	6.69	63.46	42.89	75.42	58.33
18-Jun-00	12.71	12.21	103718	102397	0.9297	0.8953	13.68	6.59	57.27	37.8	69.38	52.57
20-Jun-00	6.75	6.26	17270	13727	0.9752	1.1088	7.28	1.3	30.65	12.41	40.97	19.55
21-Jun-00	14.15	13.66	58904	50389	1.2085	1.6031	13.69	5.85	62.47	40.63	75.38	54.83
26-Jun-00	4.16	3.65	94731	93557	0.7979	0.6573	12.47	4.25	64.11	37.58	73.68	48.87
26-Jun-00	4.13	3.64	67014	53748	1.2672	1.5911	10.65	2.44	52.01	25.85	64.71	40.14
28-Jun-00	9.94	9.45	93551	83367	1.0964	1.3352	12.66	5.17	67.06	46.55	79.78	63.93

DATE	Duration (hours)		Total Truth		Forecast BIAS		Binary CSI Scoring		Box CSI Score (%)		User CSI Score (%)	
	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min
7-Jul-00	4.06	3.56	24281	21269	1.3404	2.1164	21.46	12.02	46.16	28.86	53.56	34.71
12-Jul-00	12.12	11.63	148909	150842	0.9771	0.9654	18.24	5.4	57.05	29.46	65.27	38.98
13-Jul-00	5.46	4.96	88812	84061	0.9719	0.967	21.11	7.16	72.65	43.76	80.27	53.94
15-Jul-00	8.64	8.15	108905	108857	0.932	0.8809	19.76	7.42	53.03	28.6	61.11	36.74
17-Jul-00	9.03	8.54	11590	10843	0.825	0.9689	12.86	6.12	61.83	36.05	68.28	42.96
18-Jul-00	6.89	6.38	29253	27226	1.2301	1.4108	13.83	3.74	60.72	31.4	71.05	46.11
20-Jul-00	10.61	10.11	410167	414216	0.9386	0.9426	38.53	28.06	86.38	72.82	91.64	81.53
29-Jul-00	17.86	17.35	331186	325713	1.0042	0.9724	20.06	9.42	75.89	52.45	85.16	65.89
30-Jul-00	12.9	12.41	53904	54599	0.91	0.8913	11.87	3.05	64.13	30.55	75.94	43.97
31-Jul-00	10.03	9.53	68177	68519	0.8999	0.8498	8.59	2.56	56.95	25.94	70.24	38.6
1-Aug-00	9.33	8.73	118706	115340	1.0132	1.0134	9.93	3.35	60.26	26.42	71.66	35.18
2-Aug-00	7.45	6.95	28337	28552	1.027	0.998	7.41	2.16	53.36	23.58	66.66	34.37
3-Aug-00	15.18	14.69	152457	151827	0.9805	0.9313	26.92	16.11	79.8	58.11	86.23	66.53
4-Aug-00	10.33	9.83	89022	86434	0.9217	0.8582	19.05	6.5	73.37	41.62	81.32	51.92
10-Aug-00	14.1	13.6	376460	375940	0.9647	0.9379	19.16	7.52	70.71	42.11	78.95	52.85
18-Aug-00	11.91	11.42	9379	12453	1.0661	1.0658	19.29	5.89	78.4	35.31	84.71	44.59
22-Aug-00	4.56	4.07	30500	27285	0.9255	0.8805	8.09	2.22	57.21	26.58	68.51	36.46

DATE	Duration (hours)		Total Truth		Forecast BIAS		Binary CSI Scoring		Box CSI Score (%)		User CSI Score (%)	
	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min
24-Aug-00	7.3	6.81	17529	13334	1.3462	1.7348	9.84	2.01	70.54	35.85	84.06	57.2
26-Aug-00	7.64	7.14	16919	13716	1.0861	1.2524	6.17	1.09	54.55	14.4	67.94	26.05
10-Sep-00	13.27	12.78	44139	44633	0.9392	0.9503	21.4	9.66	77.3	50.61	84.59	60.84
11-Sep-00	7.13	6.63	122160	121773	0.9326	0.8491	17.24	5.39	72.92	40.72	82.97	54.95
20-Sep-00	8.64	8.15	55416	56010	0.8977	0.8347	16.11	4.59	66.76	38.86	75.61	49.13
23-Sep-00	6.75	6.24	108350	103303	0.9074	0.891	21.56	8.67	72.44	50.58	82.8	65.49
24-Sep-00	19.86	19.34	369228	348741	1.0062	1.0271	22.61	12.76	77.53	58.2	87.21	72.03

APPENDIX D
TCWF OPERATIONALLY SIGNIFICANT DAYS MCO -2000

TABLE D-1

SITE	DATE	TIME (UTC)	SYNOPSIS
MCO	9-May-00	1630-0030	This was the first day of "summer" weather. Strong heating combined with increased moisture and cold mid/upper levels, leading to thunderstorm development. *TCWF: The storms were airmass in nature and hence the scores started off low. Initial scores were 55/25% (200nm) and 50/15% (TRACON) for 30 and 60 minutes, respectively, but increased during day as cells organized to 80/45% and 70/35%.* NOTE: One of the TCWF computers lacked processing power and was often pegged at 100% slowing the TCWF product.
MCO	3-Jun-00	2000-0100	Storms fired up along both East Coast Sea Breeze (ECSB) and the West Coast Sea Breeze (WCSB). *TCWF: Did not perform well with the quasi-stationary convection. The initial forecast moved the cells rapidly E, then N, then NNW. Forecasts improved @2300 when a line formed to the NW and TCWF captured the correct motion. Scores of 45/10% (200nm) gradually improved to 85/30% (200nm). No TRACON scores were produced due to the lack of level 3 and greater pixels, causing the threshold criteria not to be met.*
MCO	6-Jun-00	1600-2130	Prefrontal trough and abundant moisture across central FL produced several showers. *TCWF: Did much better with the activity because all showers consistently moved E-SE @ 20-25kts. Scores were low at the beginning 60/25% (200nm) and improved to 90/60% (200nm) and 60/30% (TRACON).*
MCO	7-Jun-00	1730-0000	A cold front stalled just S of MCO. Dry air N of MCO and humid air S of MCO sparked storms. *TCWF: Initial scores of 75/30% (200nm) and 75/55% (TRACON), both peaking at 85/60% and 95/65%, respectively.* NOTE: Good performance overall except @ 2130 when storms that moved N

SITE	DATE	TIME (UTC)	SYNOPSIS
			and W and hit MCO were incorrectly forecast (TCWF showed SE motion). Most activity moved SE, thus good scores.
MCO	13-Jun-00	1830-0030	A line formed 5nm NNE-SSW of MCO and a large cluster grew, about 50-60nm SW of MCO. Severe thunderstorms threatened the Tampa (TPA) area as well. *TCWF: Did a fair job as the cells grew and decayed rather quickly. Initial scores were 30/10% (200nm) but they slowly improved to 60/30% (200nm) and 75/35% (TRACON). Both peaked around 0100 at 80/45% and 50/30%, respectively.*
MCO	14-Jun-00	1800-0200	Consistent E wind hampered development on this day. There was, however, an impressive line along the WCSB located along the coast. The WCWB collided w/easterly flow around 40-60nm W of MCO. *TCWF: The correct motion (to NNW) was forecast. Scores started 35/20% (200nm) and improved to 75/45% (200nm) and 55/10% (TRACON).*
MCO	15-Jun-00	1900-2300	A weak ECSB generated a few showers. *TCWF: Did well considering a lack of level 3 weather. Scores started 75/45% (200nm) and decreased to 55/30% (200nm) as activity decayed.*
MCO	16-Jun-00	1500-2300	Another weak ECSB generated a few scattered showers. *TCWF: No scores posted through 2043. Scores reached 80/55% (200nm).*
MCO	17-Jun-00	1600-2130	Active ECSB with two waves of precipitation from the E. *TCWF: Good day, once enough level 3 weather developed. Scores started off at 70/40% (20nm) and 70/30% (TRACON). The best scores of the day were produced for the storms on the W coast at 80/70% (200nm).* NOTE: Direction was good; however, the advection was too fast especially with the first wave.
MCO	20-Jun-00	1900-0100	The ECSB and a weak WCSB caused shower development. *TCWF: Did okay with the airmass situation. Weather was not very significant. The product suffered outages because of NEXRAD problems.*
MCO	21-Jun-00	1800-0000	The ECSB and WCSB collided, producing airmass activity that became somewhat organized. *TCWF: Did a fair job with activity even though storms were very slow moving. Scores started 55/25% (200nm), and improved to 70/25%. Scores dropped around 2100 as new growth occurred.*
MCO	22-Jun-00	1700-0100	The ECSB and WCSB collided over MCO along with numerous other boundaries and thunderstorms.

SITE	DATE	TIME (UTC)	SYNOPSIS
			TCWF: Did a fair job on the slow moving storms. Scores were 70/25% (200nm) and 45/30% (TRACON). This airmass regime was very tough for the algorithm.
MCO	23-Jun-00	1530-0100	Very big weather day. Lots of severe thunderstorms in the area. *TCWF: Average scores were 70/50% (200nm) and 55/40 (TRACON).* NOTE: TCWF suffered some problems at site with machines running the algorithm. Product became available at 1920.
MCO	27-Jun-00	1300-0200	Lots of moisture and surface heating produced many showers/thunderstorms. *TCWF: NEXRAD down until 2307 due to repairs. Therefore, TCWF missed most of the event and was not very useful.*
MCO	28-Jun-00	1400-0130	The ECSB and WCSB collided just W of MCO. *TCWF: Did very well. Scores started low but improved throughout the day. Algorithm correctly showed the line moving ENE while individual cells moved N. Scores improved to 75/50% (200nm) and 85/45% (TRACON) by 2255.*
MCO	30-Jun-00	1215-0030	An approaching cold front brought large amounts of moisture to Central Florida. A line formed from coast to coast with up to levels 4/5/6. *TCWF: High scores reached 50/30% (200nm) and 75/40% (TRACON). The NEXRAD was up and down all day, making it difficult to grasp the TCWF effectiveness. While the product was available, storms were tracked accurately.*
MCO	6-Jul-00	1930-0100	The ECSB combined with hot/moist conditions to produce several showers/thunderstorms. *TCWF: Did very well with slow moving storms. Scores peaked at 85/65% (200nm) and 55/45% (TRACON).*
MCO	7-Jul-00	1900-0330	A pre-frontal trough moved through the state producing many strong storms, some of which moved over MCO. *TCWF: The algorithm did a good job with movement, motion and speed. Scores averaged 85/60% (200nm) and 65/40% (TRACON).*
MCO	7-Jul-00	1600-0045	A cold front moved down the state. There were many strong storms. In addition the ECSB and WCSB were active. *TCWF: Scores averaged 70/45% (200nm) and 75/45% (TRACON) which declined as cells decayed.* NOTE: Overall the flow was from NE to SW. TCWF moved storms to SW when in reality they were stationary.
MCO	12-Jul-00	2000-0300	Another trough to the north combined with strong surface heating to provide another active day. *TCWF: Motion was accurate thanks to a strong NW flow. Scores were high in*

SITE	DATE	TIME (UTC)	SYNOPSIS
			the 200nm range, 95/55%. Scores were lower in TRACON, 60/35% as cells decayed.
MCO	13-Jul-00	1400-2230	The trough approached from the north. *TCWF: Scores peaked at 90/60% (200nm) and 60/40% (TRACON).*
MCO	14-Jul-00	1500-0000	A repeat of the 13th. The thunderstorms along FL/GA boarder provided the extra needed boost for development. *TCWF: A nearly solid line of thunderstorms proved easy for TCWF to track; however, the quick decay played havoc for ATC. Scores averaged 85/50% (200nm) and 70/45% (TRACON).* NOTE: Decay proved to be extremely important and ATC was not happy with performance. TCWF predicted 1 hour in advance that the line would hit MCO. MCO ATC and ZJX talked with the Command Center and used TCWF to predict that MCO would close for 30-45min. Unfortunately, most of the activity decayed and ATC got burned (missed opportunity). MCO did close for about 10-15 minutes, but the damage was done.
MCO	15-Jul-00	1200-2200	A persistent trough in North Florida proved to be once again the instigator of activity during the day. *TCWF: Did an impressive job. TCWF had a good handle on what was going on. Initial scores were 90/65% (200nm) and 90/60% (TRACON) but as cells decayed, scores dropped to 85/70% and 65/50%, respectively.*
MCO	18-Jul-00	1730-2330	A stationary trough continued to influence the weather. *TCWF: Had a good day. Scores were mostly produced at the 200nm range, and averaged 85/60%. Scores went up/down as cells evolved.*
MCO	19-Jul-00	1830-0100	Colliding gustfronts created large storms. *TCWF: Completely missed the new weather that formed because of Gust Front (GF) collision over MCO. Scores averaged 75/45% (200nm) and 60/40% (TRACON).*
MCO	20-Jul-00	1900-0245	Outflow from strong thunderstorms in North Florida created a strong gustfront that raced down the state and set the stage for severe weather. *TCWF: Scores averaged 65/50% (200nm) and 50/30% (TRACON).* NOTE: TCWF showed thunderstorms moving SSW when actually they remained stationary or moved E.
MCO	21-Jul-00		Unfortunately the NEXRAD went down. This was a good weather day.
MCO	22-Jul-00	1230-0030	Deep moisture produced severe weather early in the day. A line stretching 50nm wide across the state created problems for ATC.

SITE	DATE	TIME (UTC)	SYNOPSIS
			TCWF: Scores averaged 75/45% (200nm) and 75/60% (TRACON). There was a large increase in scores once the line formed.
MCO	25-Jul-00	1900-2330	Sea breezes and deep tropical moisture produced lots of showers/thunderstorms. *TCWF: Forecast motion was good. Scores averaged 85/50% (200nm) and 75/60% (TRACON).*
MCO	26-Jul-00	1600-0130	A stationary front across North Florida combined with the sea breezes to provide for an active afternoon. *TCWF: Forecast motion was fine. Scores averaged 75/50% (200nm) and 60/45% (TRACON).*
MCO	27-Jul-00	1830-0000	Some drying in the atmosphere yielded less than expected weather. *TCWF: Scores averaged 80/40% (200nm) and 75/60% (TRACON).*
MCO	28-Jul-00	1800-0000	The ECSB was the main catalyst for convection during the day. *TCWF: Too few level 3 pixels in TRACON to produce scores. 200nm range scores averaged 65/35%. The WCSB was very active in the evening and TCWF handled it well.*
MCO	29-Jul-00	1600-0230	Another perfect example of the ECSB/WCSB collision giving a 45-minute lead time before precipitation hit the ground. *TCWF: Handled it fairly well with accurate forecast motion. Scores averaged 80/55% (200nm) and 65/40% (TRACON).*
MCO	1-Aug-00	1600-0045	A trough axis rotated around a ridge axis across central Florida. *TCWF: Scores were not produced right away due to the lack of level 3. Scores averaged 85/65% (200nm) and 75/60 (TRACON).*
MCO	2-Aug-00	1700-2000	The trough combined with the ECSB and WCSB to create a lot of weather. *TCWF: Unfortunately, the NEXRAD went down at 2000. ZJX used TCWF a lot during the afternoon and thought it was fairly accurate. Scores averaged 80/55% (200nm) and 60/40% (TRACON).*
MCO	3-Aug-00	1545-0315	Isolated convection began as a ridge axis drifted northward. Daytime heating gave way to the development of a broken line. Two stronger lines developed later in the day and merged, growing in strength, size and speed. *TCWF: High scores of the day reached 80/55% (200nm) and 60/40% (TRACON).*
MCO	4-Aug-00	1600-0200	A ridge axis shifted N across central Florida. The northern edge of the ridge was the focal point for convection.

SITE	DATE	TIME (UTC)	SYNOPSIS
			TCWF: This was a hybrid situation—line to North and airmass storms to the South. Scores averaged 75/35% (200nm). Users were pleased with product during the day.
MCO	5-Aug-00	1700-0100	A shortwave trough shifted the ridge axis back down across central Florida. Most precipitation was concentrated over MCO. *TCWF: Scores averaged 65/40% (200nm) and 65/25% (TRACON).* NOTE: Motion was mostly stationary but TCWF wanted to move the storms. Scores seemed too high.
MCO	9-Aug-00	1630-0000	Tropical Depression #4 formed 100nm E of Kennedy Space Center (KSC). Additional thunderstorms near Tampa, backbuilt from the NW towards MCO. *TCWF: Scores averaged 80/40% (200nm) and 60/15% (TRACON).* NOTE: Unfortunately, the motion was incorrect. TCWF moved the cells (out west) to the SE while they actually built E.
MCO	10-Aug-00	1930-0000	Sea breeze interaction existed while Tropical Depression #4 moved NE away from Florida. *TCWF: Too few level 3 pixels, therefore, scores were only available at the 200nm range. They were 65/30% on average.*
MCO	11-Aug-00	1600-0000	The WCSB moved through with minimal precipitation. *TCWF: The motion was accurate but too few pixels of level 3 and greater for scores to be produced. Finally scores were posted for 200nm at 80/30%.*
MCO	12-Aug-00	1300-2200	The cold front stalled in southern Georgia and allowed deep, moist flow to stream across FL from the Gulf of Mexico. TCWF: The west to east wind field allowed motion to be accurate. Scores averaged 80/65% (200nm) and 65/55% (TRACON).
MCO	15-Aug-00	1900-2200	Strong NE winds because of the high pressure system to the North. The ECSB produced a few showers. *TCWF: Very few pixels but 200nm scores were 85/45%.*
MCO	22-Aug-00	1400-2330	Weather off the East coast combined with easterly flow to bring rain westward across the state. *TCWF: Excellent job for this airmass case! Scores averaged 80/50% (200nm) and 80/65% (TRACON). Scores were unexpectedly high. This can be attributed to the fact that the activity did not decay, it just continued to move W through the state.* NOTE: TCWF was right on with the forecast for this airmass event.

SITE	DATE	TIME (UTC)	SYNOPSIS
MCO	23-Aug-00	1400-0100	This situation was similar to that on the 22nd - with weather moving onshore on the east coast and traveling west. The mid/upper levels were slightly drier and thus there was less weather. *TCWF: Too few level 3 pixels. Scores finally posted at 65/35% (200nm) and 70/40% (TRACON). There were more challenges today as some cells decayed as they moved westward.*
MCO	24-Aug-00	1630-2230	Easterly winds kept the ECSB from forming but light showers did move westward across state. *TCWF: The scattered activity only produced 200nm scores, averaging 90/55%.*
MCO	25-Aug-00	1900-0300	A trough approaching the Big Bend (area where west coast starts to turn into the panhandle) produced strong storms across north Florida and eventually over MCO. Most activity remained to the north of MCO. *TCWF: Movement was good. Scores averaged 85/65% (200nm) and 85/70% (TRACON).*
MCO	26-Aug-00	1800-2230	The ECSB caused showers and airmass storms during the afternoon, becoming somewhat organized in nature. *TCWF: Handled storms very well considering slow (~5 knots) movement. Scores averaged 70/30% (200nm) and 90/20% (TRACON).*
MCO	29-Aug-00	1100-0130	Strong thunderstorms raced down the state from the Georgia/Florida boarder from an impulse from an upper level low over Georgia. *TCWF: Excellent example of two separate line events, and how they were handled well by the algorithm. Scores averaged 90/75% (200nm) and 90/80% (TRACON).*
MCO	30-Aug-00	1530-0330	A surface low off the South Carolina coast combined with the trough over central Florida to create a lot of weather. *TCWF: Excellent job once again. Tracking and motion were extremely accurate. Scores peaked at 80/60% (200nm) and 95/85% (TRACON).*
MCO	31-Aug-00	1700-0000	Weak showers moved onto the west coast and moved NE due to circulation around a low over Georgia. *TCWF: Movement was good although there were too few level 3 pixels. Scores averaged 75/50% (200nm).*
MCO	1-Sep-00	1600-0030	A low pressure system over Georgia continued to pull in a lot of weather from the Gulf. *TCWF: Another good day with good motion. Scores averaged 80/50% (200nm) and 85/60% (TRACON). Scores did not vary much.*

SITE	DATE	TIME (UTC)	SYNOPSIS
MCO	2-Sep-00	1230-0100	The southwest flow persisted with lots of weather moving in from the Gulf of Mexico. *TCWF: Motion was accurate. Scores only posted at 200nm at 90/55%.*
MCO	5-Sep-00	1630-0330	A trough in NE Gulf continued to feed clouds/rain across the state. Also, the sea breezes were active during the day. *TCWF: Lots of weather and TCWF handled it well. The motion was very accurate. Scores averaged 85/55% (200nm) and 85/50% (TRACON).*
MCO	6-Sep-00	1500-0100	A front across northern Florida and a low in the Eastern Gulf of Mexico produced a lot of weather during the day. *TCWF: Good day, motion and speed were accurate. Scores averaged 85/65% (200nm) and 85/75% (TRACON).*
MCO	7-Sep-00	1200-2330	Lots of moisture associated with low situated in Eastern Gulf of Mexico combined with the SW flow. All of the weather moved over Florida. *TCWF: Algorithm performance was average. Scores averaged 85/45% (200nm) and 85/55 (TRACON). Scores were more impressive later, as a line formed N-S near the west coast, Tampa area.* NOTE: Movement was too fast while most of the storms were fairly stationary.
MCO	8-Sep-00	1530-0130	A low in the Gulf retrograded westward and took some of the moisture with it. *TCWF: TCWF motion was good. Too few level 3 pixels so only 200nm scores were posted, 65/35%.*
MCO	9-Sep-00	1130-0230	A decaying front across the region combined with easterly flow off the Atlantic to produce showers/thunderstorms. *TCWF: The algorithm handled the situation much like it was a line event. Scores averaged 85/70% (200nm) and 90/70% (TRACON).* NOTE: ATC commented: “TCWF right on tonight”.
MCO	16-Sep-00	1210-0400	Hurricane Gordon formed in the Southern Gulf of Mexico and moved toward the west coast of Florida. *TCWF: Several NEXRAD problems occurred early on. Scores later, averaged 80/55% (200nm) and 85/35% (TRACON). The motion was accurate.*
MCO	17-Sep-00	0930-0300	Hurricane Gordon approached Florida. *TCWF: Most of the envelope motion was correct but scores still seemed a bit high, 75/65% (200nm) and 80/70% (TRACON).*
MCO	19-Sep-00	1630-0330	The ECSB launched most of the weather during the day. *TCWF: NEXRAD had problems all day. When the radar was up, scores*

SITE	DATE	TIME (UTC)	SYNOPSIS
			averaged 85/55% (200nm) and 90/65% (TRACON).
MCO	20-Sep-00	1400-0100	The ECSB formed a N-S line of thunderstorms. *TCWF: Product performed well all day. Scores dropped as cells began to decay. Scores averaged 80/60% (200nm) and 85/70% (TRACON).*
MCO	21-Sep-00	1500-0030	Tropical Depression #12 was upgraded to Tropical Storm Helene in the central Gulf of Mexico. Counterclockwise circulation pulled most of the precipitation across central Florida. *TCWF: Scores averaged 85/50% (200nm) and 80/50% (TRACON).* NOTE: Direction was good but motion was too fast.
MCO	22-Sep-00	1400-0130	Helene moved onto the northern coast near Panama City but most of the convection was N and E of the center, over central Florida. *TCWF: Some NEXRAD outages were experienced during the day but scores averaged 85/60% (200nm) and 90/50% (TRACON).*
MCO	23-Sep-00	1730-0200	The WCSB moved through; however, not much weather was associated with it. *TCWF: Scores averaged 85/35% (200nm) and 90/15% (TRACON).*
MCO	26-Sep-00	1600-0030	A cold front pushed into Northern Florida. *TCWF: Too few level 3 pixels. Scores finally were produced after several hours for the 200nm range.*
MCO	29-Sep-00	1600-0230	Moderate NE wind flow and trough along the East coast produced waves of showers all day. Most of the cells decayed in place or drifted slowly west. *TCWF: Scores averaged 80/60% (200nm). The NEXRAD was down for 2 hours for additional maintenance.* NOTE: Algorithm experienced motion problems. TCWF moved cells E and ENE while storm motion vectors were in the opposite direction.
MCO	30-Sep-00	1200-0000	Gusty NE winds and rain caused by high pressure in the Northeast set the weather scenario for most of the day. *TCWF: Not much level 3. Scores were only posted for a few minutes.*

TABLE D-2
Daily Forecast Accuracy Statistics for MCO - 2000

DATE	Duration (hours)		Total Truth		Forecast BIAS		Binary CSI Score (%)		Box CSI Score (%)		User CSI Score (%)	
	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min
9-May-00	8.73	8.22	69066	74432	1.0566	1.1074	11.04	2.6	57.66	24.8	68.82	36.03
6-Jun-00	7.24	6.73	91423	91666	0.8864	0.7927	24.73	9.66	72.72	42.92	80.82	54.49
7-Jun-00	9.46	8.95	132937	135591	1.0058	1.0438	15.29	7.03	72.76	45.63	81.41	56.61
13-Jun-00	6.06	5.46	101961	105112	0.9449	0.9206	17.28	3.98	65.49	30.09	73.81	40.69
14-Jun-00	7.28	6.77	73301	72764	0.8846	0.832	17.27	7.38	66.86	41.32	73.8	48.32
17-Jun-00	7.3	6.78	124389	127307	0.8496	0.8145	18.63	7.72	68.01	40.28	76.54	50.16
22-Jun-00	9.03	8.52	63667	59633	0.9781	1.0789	6.52	1.55	56.32	21.67	67.53	31.04
23-Jun-00	10.18	9.67	417805	416573	0.9608	0.9685	15.66	5.99	58.2	30.94	70.18	44.9
27-Jun-00	2.04	1.53	13504	9207	1.282	1.6711	8.82	2.52	50.33	23.32	66.53	40.66
28-Jun-00	11.18	10.66	123087	125522	1.0033	1.1004	10	2.52	61.32	30.41	73.63	44.83
30-Jun-00	11.91	11.4	100743	96789	1.0891	1.1743	12.62	4.35	50.98	26.83	65.25	42.89
7-Jul-00	9.59	9.08	354914	354419	0.9869	1.0394	19.99	8.28	67.56	43.46	76.16	55.28
8-Jul-00	8.95	8.35	217633	214525	1.0212	1.1061	12.22	4.04	61.31	31.73	72.79	43.85
12-Jul-00	7.8	7.28	32343	28577	1.0376	1.2158	13.06	2.64	67.63	35.56	77.46	46.67
14-Jul-00	9.04	8.52	173617	165933	1.1037	1.1671	13.7	4	59.9	31.94	72.37	45.27
15-Jul-00	11.63	11.11	469871	449345	1.0178	1.011	26.08	10.64	76.75	49.49	84.81	62.02
18-Jul-00	6.38	5.85	176637	167777	0.9811	1.0102	23.5	10.94	76.48	52.42	83.41	62.1
19-Jul-00	7.87	7.44	93506	86454	0.9585	0.9605	13.2	3.21	65.62	33.04	75.22	42.95
20-Jul-00	9.02	8.51	315163	309967	0.9755	0.9966	19.39	7.79	59.78	35.43	69.31	45.99
21-Jul-00	0.85	0.34	16627	10644	0.5887	0.4507	7.21	1.97	69.44	31.92	79.61	42.57
22-Jul-00	12.79	12.28	274465	265578	1.0774	1.1198	12.5	3.71	62.67	33.74	73.65	46.9
25-Jul-00	6.15	5.7	160979	149222	0.9842	1.0281	13.8	4.58	68.88	40.44	80.39	55.54
26-Jul-00	10.25	9.74	210463	208044	1.0312	1.0723	11.7	3.98	64.8	34.27	76.79	47.19
27-Jul-00	5.46	4.86	87767	80967	0.8866	0.7102	14.4	4.04	67.73	31.6	77.74	43.38
29-Jul-00	10.04	9.53	144190	144727	1.0537	1.1451	12.1	6.18	64.7	37.81	74.78	48.1

DATE	Duration (hours)		Total Truth		Forecast BIAS		Binary CSI Score (%)		Box CSI Score (%)		User CSI Score (%)	
	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min
1-Aug-00	8.05	7.53	139685	138886	0.9841	0.9732	15.13	6.76	69.57	37.88	80.35	50.33
2-Aug-00	7.37	6.86	89216	76886	0.9123	0.7595	9.67	2.65	65.1	32.83	78.18	48.27
3-Aug-00	11.49	10.98	119259	121507	0.971	0.9582	11.58	2.54	68.04	32.22	79.86	47.26
4-Aug-00	10.7	10.19	100725	96522	1.0077	1.0598	8.76	1.73	59.85	22.85	71.74	36.49
5-Aug-00	8.13	7.62	176516	173149	1.0101	0.9821	12.39	4.14	64.96	31.44	76.06	43.34
9-Aug-00	8.29	7.78	123658	120170	1.0415	1.1054	16.35	4.82	66.49	31.45	77.6	45.52
22-Aug-00	9.66	9.15	94634	92720	1.0471	1.14	10.79	3.75	62.87	31.96	76.29	44.67
23-Aug-00	11.62	11.11	82296	81398	0.9568	0.9626	15.83	6.88	73.34	49.49	83.67	62.39
25-Aug-00	8.05	7.71	218773	220869	1.0398	1.0467	20.88	9.03	72.11	46.83	80.77	58.2
26-Aug-00	5.94	5.43	96196	93691	1.0168	1.0578	14.33	3.35	69.51	33.51	79.19	44.99
29-Aug-00	13.95	13.44	302895	279162	1.0136	1.0425	26.53	12.77	78.7	53.1	86.5	64.22
30-Aug-00	11.97	10.95	44463	40812	1.0185	1.1064	13.24	5.1	70.29	43.14	81.43	56.21
1-Sep-00	8.8	8.29	122420	121162	0.9519	0.8802	17.12	6.22	74.59	42.65	83.43	53.44
2-Sep-00	13.03	12.52	127509	114393	1.1351	1.3345	13.76	4.1	67.06	34.94	79.74	50.88
5-Sep-00	11.01	10.5	343147	331875	0.9803	0.928	17.96	6.21	77.17	46.96	85.98	60.48
6-Sep-00	9.8	9.21	317180	320151	0.9681	0.906	14.36	7.03	71.42	45.13	82.6	58.97
7-Sep-00	12.27	11.76	215954	203074	1.0176	1.0006	11.9	3.27	65.72	33.5	79.35	50.05
16-Sep-00	14.94	14.43	202201	190818	1.032	1.0511	11.2	3.45	64.38	33.93	76.84	50.19
17-Sep-00	17.09	16.58	329557	299894	1.1156	1.2443	14.26	6.22	68.34	47.6	81.26	64.95
19-Sep-00	7.93	7.42	53354	53921	1.1612	1.3125	15.52	5.5	70.88	41.24	82.23	55.41
20-Sep-00	10.88	10.37	158880	158286	1.0577	1.225	17.09	5.92	72.53	46.01	84.01	62.27
21-Sep-00	9.32	8.88	43165	41865	0.9875	1.065	15.24	2.89	69.16	35.05	81.08	47.95
22-Sep-00	12.06	9.17	164035	158186	0.985	0.9468	12.63	4.03	70.59	42.42	82.61	58.91
23-Sep-00	8.12	7.61	64175	62740	0.9972	0.9537	18.26	7.45	74.68	46.71	83.39	58.05
29-Sep-00	10.17	9.66	69041	67199	1.0074	1.0236	11.28	4.48	61.81	31.64	76.56	48.35

APPENDIX E
TCWF OPERATIONAL SIGNIFICANT DAYS DFW-2000

TABLE E-1

SITE	DATE	TIME (UTC)	SYNOPSIS
DFW	2-May-00	0100-0440	Multi-cell and isolated storms were long lived today. *TCWF: The algorithm did a good job during the mission with strikingly different scores between the TRACON and 200nm forecasts. The 200nm forecasts remained rather high with scores falling from 95% and 90% (30 and 60 minutes) to 90% and 80% while the TRACON scores dropped from 85% and 75% (30 and 60) to70% and 60%. Scores dropped as cells decayed.*
DFW	3-May-00	1028-0637	During the morning hours, a few level 3-5 cells existed to the west. Intense thunderstorm activity developed during the afternoon hours. *TCWF: Forecast scores for the TRACON and 200nm ranges were similar, both hovering around 85/75%.*
DFW	4-May-00	1038-1950	The day consisted of isolated and multi celled storms mostly south and east of DFW. *TCWF: Forecast scores for both the TRACON and 200nm ranges during the evening event were comparable to each other with values of 85/75% for the TRACON range and 95/ 85% for the 200nm range. During the morning, there was a vast difference in scores. At 1702, the scores for the TRACON range were 45/40% while the 200nm range scores were 90/ 70%. The enroute center explained that they really like the new TCWF SD.*
DFW	5-May-00	1010-2200	A line of cells existed west of DFW in the morning. Isolated and multi cell storms developed during the afternoon. *TCWF: At start up, the forecast numbers averaged 75/65% for the TRACON product and 90/70% for the 200nm product. By 1511, the numbers fell to 65/35% for the TRACON and 85/ 55% for 200nm. The forecast numbers remained in this range until after 2100 when the lack of enough level 3 and greater pixels in the TRACON range caused the scores to be unavailable. However, strong storms within 200nm allowed for scores of the 200nm forecast throughout the mission. Scores dropped during the afternoon.* NOTE: There were problems with a disk filling up at startup that delayed the start of the TCWF system. Brief discussions with the TRACON and ARTCC TMC's indicated that they were very happy with the ITWS and TCWF systems during the morning mission. Most of the delays were due to weather enroute and thus the TRACON was not impacted as greatly as the ARTCC airspace was.

SITE	DATE	TIME (UTC)	SYNOPSIS
DFW	12-May-00	2120-0440	A strong line of cells developed west of DFW and tracked eastward. *TCWF: The TCWF again did a very good job of tracking the developing storms. By 0059, the forecast scoring numbers were 80/55% for the 200nm product and 65/15% for the TRACON product. The lower numbers in the TRACON product were due to fewer storms within the TRACON area. However, by 0137 the TRACON numbers jumped to 80/50% as more storms developed within the TRACON. By shutdown the numbers were 70/60% (200nm) and unavailable for the TRACON product due to the lack of enough level 3 and greater pixels. As the storms developed well east and south of the DFW and Dallas-Love Airports (DAL), there were little benefits from the TRACON TMU. The TRACON indicated, at the end of the mission, that both the TCWF and ITWS systems were used during the mission and that it did help them coordinate with the ARTCC. The ARTCC said "We love the ITWS and TCWF and it was a great benefit to us during this mission".*
DFW	18-May-00	1900-0950	Isolated storms developed into a broken line north and west of DFW. The line redeveloped around 0100 just north of DFW. *TCWF: Scores were very consistent and fairly high. 85/65% (200nm) and 85/55% (TRACON) were about the typical scores throughout the event.* NOTE: There was a very unusual artifact in the forecast product around 2245-2250. Refer to the section in the MEM Assessment Report that discusses the particular problems and solutions.
DFW	19-May-00	1730-0430	The day consisted of mostly embedded cells with some line type development all tracking northeastward through the TRACON. Some isolated strong cells developed during the afternoon and night. *TCWF: The algorithm did very well during the morning portion of the mission but as the weather intensified and diminished throughout the afternoon the forecast numbers were lower. Morning forecast numbers ranged 80-90% (30 min) and 55-70% (60 min). Afternoon numbers were 40-55% (30 min) and 30-40% (60 min).*
DFW	27-May-00	1606-0402	A weak line developed during the morning hours. During the afternoon and evening, a cold front tracked in from the west. *TCWF: Typical scores were 80/55% (200nm) and 65/30% (TRACON).*
DFW	3-Jun-00	1100-1050	Embedded cells developed during the morning with isolated cells during the day. Stronger multi cell storms developed during the evening. *TCWF: The product worked very well through the mission. Forecast scores ranged between 55/35% to 80/45% for the 200nm product and 65/45% for the TRACON product. There were many more cells for the product to work with in the 200nm range. The ARTCC used both ITWS and TCWF extensively through the night.* NOTE: The only note of interest was that there was some rotation to the large area

SITE	DATE	TIME (UTC)	SYNOPSIS
			of precipitation as the upper-level low approached north Texas. The TCWF product did not forecast this.
DFW	4-Jun-00	1050-2100	Mostly embedded cells during the early morning with scattered convection ruling the airspace for the late morning and afternoon. A weak line developed during the afternoon hours. *TCWF: The product did a fairly good job with the storms during the mission. Forecast numbers reached as high as 80/60% for the TRACON and 85/65% for the 200nm product.* NOTE: Due to the proximity of the upper-level low, the TCWF product tracked the large-scale motion of the system to the east but this caused some problems with isolated cells west and north of the low (and therefore DFW) that were rotating around the low.
DFW	9-Jun-00	1800-0300	Weak lines of convection and multi-celled storms tracked northward impacting DFW. *TCWF: Did very well throughout the mission. The TRACON used the ITWS and TCWF to determine when the airport would need to be shut down and when to open up the airport. The ARTCC TMU said the ITWS and TCWF was invaluable in coordinating with the TRACON TMC when shutting and opening the airport.*
DFW	10-Jun-00	1327-0230	Scattered weak precipitation tracked northward on this day. Stronger cells developed during the afternoon with lots of embedded cells. *TCWF: Typical scores were 80/65% (200nm), 85/70% (TRACON). The product did a good job forecasting the motion of the storms.* *The TRACON used the storm motion and TCWF to determine which runways would open and close and to pinpoint the time it would happen.*
DFW	11-Jun-00	1230-0130	Embedded cells existed east of DFW during the morning hours. Later in the day, isolated storms developed to the west. *TCWF: Another good day for the algorithm*.
DFW	14-Jun-00	1630-0940	A line developed around noon and crossed the TRACON. Cells tracked eastward while the line tracked south. A deep moisture layer, combined with an encroaching cold front provided the ingredients for showers and thunderstorms during the evening. *TCWF: The product worked well during the mission. Forecast numbers were as high as 90/70 % for the 200nm forecast and 85/70% for the TRACON forecast. The forecast numbers decreased during the late night as the number of level 3 and greater cells dropped off. During the early morning hours the number of cells increased and so did the forecast numbers. The TMC that was on during the DFW impact was not available after the mission and would not be for the next two weeks. However, after speaking with him briefly during the night, we learned that*

SITE	DATE	TIME (UTC)	SYNOPSIS
			the system was used to plan the runway reconfiguration well before the cold front impacted the ARENAS. They used both systems extensively. NOTE: The high confidence forecasts of level 3 and greater weather showed an increase in area coverage with time. The effect was that the product looked as though it was predicting growth.
DFW	15-Jun-00	1030-2130	End of the embedded event from the 14th. Isolated cells developed during the late morning and early afternoon. *TCWF: No scores due to the weak and scattered nature of the convection.*
DFW	17-Jun-00	1330-2330	Wide spread convection ahead of a cold front ruled the day. Some linear storms developed, but most were isolated in nature. *TCWF: High scores throughout the mission. Typical scores were 85/70% (200nm) and 85/80% (TRACON).*
DFW	18-Jun-00	1230-0200	A line of storms developed southwest of the TRACON during the morning, with isolated convection developing in the TRACON during the afternoon. *TCWF: The strong storms within 200nm of DFW had TCWF forecast numbers as high as 70/40%. The product had accurate motion forecasts as well.*
DFW	19-Jun-00	1730-0230	Isolated and multi cell storms tracked northward on this day. *TCWF: The algorithm produced modest scores, 70/50% (TRACON) and 75/45% (200nm).*
DFW	20-Jun-00	1759-2106	A few isolated cells developed in the afternoon. *TCWF: Not enough level 3 and greater weather to produce scores.* NOTE: Although the day was not operationally significant, there was a problem noted at 1759 where a small cell (only a few pixels) blossomed into a rather long line of storms (~35nm long) through the 60 minute forecast. Refer to the MEM Assessment Report for details.
DFW	21-Jun-00	1700-0400	As a line moved in from the north, isolated convection occurred during the afternoon and evening. Development occurred behind the line during the evening hours. *TCWF: The product did a good job during the mission. As cells tracked to the east-northeast, they also spread to the south behind the outflow boundary. As a result, the algorithm had trouble due to the continued new development. But, the system tracked the new development well. Forecast numbers looked good overall. Forecast accuracy numbers started for the 200nm product at around 2032 at only 55/ 30%. By 2146, there were forecast accuracy numbers of 55/25% for the*

SITE	DATE	TIME (UTC)	SYNOPSIS
			TRACON product. The numbers climbed throughout the mission to approximately 80/60% for both TRACON and 200nm products.
DFW	27-Jun-00	1500-0230	An outflow boundary from thunderstorms well to the north of the area was the triggering mechanism for thunderstorm development across the TRACON by early afternoon. *TCWF: All storms were moving very slowly with motion vectors of 5 knots or less with a general drift to the ESE. At 2053, the TCWF product was incorrectly speeding most of the activity off to the northeast. Within the Terminal area, while most of the activity was forecast to move to the northeast, an area 20nm NW of DFW was advected to the northwest. The ARTCC used ITWS and TCWF extensively and they also felt that it helped in their coordination with the TRACON. They also mentioned they "feel blind" when the system is not operational.*
DFW	28-Jun-00	1200-2350	Showers and a few thunderstorms, associated with an advancing cold front developed during the morning hours. *TCWF: The product worked well during the mission. TRACON scores were unavailable during the mission due to the lack of weather. The 200nm product received forecast scores as high as 70% for the 30-minute product. Due to the short lifespan of the cells, the 60-minute product was not observed to score above 50%. The TRACON and ARTCC indicated that they did use ITWS and TCWF to keep an eye on the storms around the area.*
DFW	30-Jun-00	1200-2020	Multi celled and embedded storms developed with isolated cells to the west. *TCWF: In the morning scores averaged about 65/55% for the TRACON and 80/65% for the 200nm.*
DFW	1-Jul-00	1400-0100	Embedded storms 50 to 100nm to the northwest grew during the morning hours. Strong, isolated cells developed during the evening. *TCWF: Scores topped out at 90/75% for the 200nm product. Later in the mission, when a few isolated cells developed, the 60 minute scores dropped some. Overall the product looked good during the mission.*
DFW	22-Jul-00	1230-2230	A Mesoscale Convective System moved through Oklahoma during the morning hours. Associated thunderstorms tracked toward DFW. *TCWF: Scores were quite good. 200nm scores averages 85/75%.*
DFW	25-Jul-00	1600-2330	Thunderstorm development occurred in the late afternoon. *TCWF: Scores were good. Averages observed for the 200nm range were 80/50%.*
DFW	8-Aug-00	2300-0100	A line of cells developed 75nm south and southeast during the evening and decayed well south of DFW. *TCWF: Did a good job with the motion of the long-range weather and the timing*

SITE	DATE	TIME (UTC)	SYNOPSIS
			of the TRACON impact. Forecast numbers were around 80% for the 30-minute forecast and 60% for the 60-minute forecast. As the cells on the TRACON border decayed slowly, forecast numbers suffered.
DFW	1-Sep-00	1800-2300	Mostly stationary, isolated, short-lived cells ruled the day. *TCWF: With the scattered nature of convective activity, the algorithm scores did not get very high, only peaking to 55/30% for the 200nm range. No scores were produced for the TRACON range.*
DFW	2-Sep-00	1930-0115	Isolated showers and thunderstorms developed south and west of the metroplex during the afternoon hours. *TCWF: The isolated nature of the storms kept scores on the low side, averaging 60/30% (200nm).*
DFW	20-Sep-00	0100-0300	Strong isolated storms that developed 80nm to the southeast were primarily stationary. *TCWF: The TCWF produced forecast numbers by 2245 making a forecast for the cells 70+nm southeast of DFW. Forecast numbers started out at 55% at 30 minutes and grew to 85% for 30 minutes and 55% for 60 minutes by 0018. The product did a good job capturing the motion of the cells.*
DFW	23-Sep-00	2200-0900	A line of storms developed along a cold front and tracked NE as the cold front slipped south. *TCWF: Did a good job during the mission. Forecast numbers were as high as 95/65% for the TRACON range and 85/55% for the 200nm range. The low 60 minute scores were due to the quick growth of the storms.*
DFW	24-Sep-00	0900-0340	Isolated cells existed during the morning with a large area of cells developing to the north between 1200 and 1800. During the afternoon and evening a line of cells developed southeast of the TRACON.

TABLE E-2
Daily Forecast Accuracy Statistics for DFW-2000

DATE	Duration (hours)		Total Truth		Forecast BIAS		Binary CSI Score (%)		Box CSI Score (%)		User CSI Score (%)	
	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min	30 Min	60 Min
3-May-00	2.99	2.41	23358	19801	1.0403	0.9576	19.38	10.93	81.62	68.92	87.47	77.97
4-May-00	10.47	9.97	207702	193167	1.0871	1.233	22.44	9.65	71.19	45.26	79.61	57.61
5-May-00	12.07	11.57	239039	219293	1.0549	1.1903	23.2	9.4	64.05	38.31	73.21	49.97
12-May-00	17.41	16.92	315216	274189	0.8166	0.6869	44.32	26.39	75.68	54.25	81.94	63.41
20-May-00	2	1.5	32440	21463	1.0625	1.3976	8.75	1.26	30.81	11.86	51.06	32.25
27-May-00	6.59	6	182724	171932	0.8553	0.7854	24.35	10.62	65.68	41.21	72.97	50.05
27-May-00-	4.67	4.09	344973	286631	0.9888	1.1092	27.42	17.02	70.52	49.33	78.64	60.87
9-Jun-00	15.89	15.41	111621	110262	1.1829	1.4204	14.45	4.93	57.46	32.45	69.14	46.51
11-Jun-00	12.29	11.79	206182	197165	1.1412	1.2978	19.15	8.96	64.89	43.6	75.92	58.45
14-Jun-00	22.22	21.74	402053	403148	1.0026	1.0441	24.91	10.6	74.79	49.48	82.71	61.7
15-Jun-00	11.91	11.43	29912	23859	1.1738	1.4086	23.25	9.72	68.87	40.24	79.24	51.56
17-Jun-00	11.13	10.64	388820	379364	1.0424	1.1487	20.6	9.53	67.6	44.61	77.44	57.52
18-Jun-00	12.71	12.22	147573	142903	1.134	1.2746	12.76	4.46	64.31	38.82	75.54	54.38
21-Jun-00	16.18	15.69	302450	299916	1.0271	1.1327	20.08	10.9	59.36	40.62	68.93	51.97
27-Jun-00	15.17	14.69	184844	186858	1.0381	1.0781	15.13	5.18	64.61	37.27	74.42	50.01
28-Jun-00	14.51	14.02	124899	107165	1.0187	1.2707	24.16	15.87	54.49	39.55	66.59	53.03
1-Jul-00	10.71	10.22	47702	43560	1.118	1.3051	13.94	6.59	65.08	41.84	77.24	56.6
14-Jul-00	13.83	13.35	5606	5248	0.7751	0.6103	7.82	0.36	62.29	16.27	76.4	31.07
22-Jul-00	9.82	9.33	72119	47490	1.1433	1.5437	37.37	25	75.85	64.28	84.44	75.65
25-Jul-00	11.37	10.89	12406	12341	0.8996	0.8987	23.73	5.9	74.44	36.86	80.91	48.11
1-Sep-00	12	11.52	9715	9277	0.8703	0.9034	1.55	0.59	29.17	11.79	45.42	19.73
2-Sep-00	5.36	4.87	32592	27976	0.8979	0.9146	5.71	1.05	47.29	16.17	61.23	28.8
23-Sep-00	29.3	28.82	385634	380426	1.0009	0.9851	19.4	8.24	78.42	52.25	87.97	67.62

GLOSSARY

ARTCC	Air Route Traffic Control Center
ASR-9	Airport Surveillance Radar -9
ATC	Air Traffic Control
AWRP	Aviation Weather Research Program
CDM	Collaborative Decision Making
CSI	Critical Success Index
CWSU	Center Weather Service Unit
DAL	Dallas-Love Airport
DFW	Dallas-Fort Worth Airport
ECSB	East Coast Sea Breeze
FAA	Federal Aviation Administration
FedEx	Federal Express
FFT	Fast Fourier Transform
GF	Gust Front
IOC	Initial Operational Capability
ITWS	Integrated Terminal Weather System
LL	Lincoln Laboratory
MCO	Orlando Airport
MEM	Memphis Airport
MIT	Massachusetts Institute of Technology
N/A	Not Available
NCAR	National Center for Atmospheric Research
NEXRAD	Next Generation Weather Radar
NWA	Northwest Airlines
NWS	National Weather Service
NYC	New York City Airports
ORD	Operational Requirements Document
P^3I	Pre-Planned Product Improvement
PDT	Product Development Team
RBDT	Ribbon Display Terminal
SD	Situation Display
TCWF	Terminal Convective Weather Forecast
TMU	Traffic Management Unit
TPA	Tampa Airport
TRACON	Terminal Radar Approach Control
VIL	Vertically Integrated Liquid Water
VIP	Video Integrator Processor

WCSB	West Coast Sea Breeze
WJHTC	FAA William J. Hughes Technical Center
ZJX	Jacksonville Air Route Traffic Control
ZME	Memphis Air Route Traffic Control Center

SITE	DATE	TIME (UT)	SYNOPSIS
			ITWS and TCWF products. Since the squall line hit during the NWA evening push, the Users were able to proactively make decisions that would allow the airspace to be utilized as best as possible. Here are some highlights from the interviews: *NWA - Used the products extensively for crew briefings both pre-flight and en-route. They reported 2 diversions to alternate airports, with as many as 6 saved diversions based on use of the ITWS/TCWF products.* *TMU - Used the products to determine which gates would open first and, thus, proactively route traffic towards these gates. This allowed aircraft to enter the airspace sooner, thereby reducing hold times. They also used the products extensively to determine where and when to hold aircraft.* *TRACON - Used the products to minimize hold times, regulate flow with the Center, and land more aircraft prior to runway closure.*
MEM	13-May-00	0101-0946	A strong cold front sparked a line of strong to severe convection that extended from Michigan to Texas. Also, cells were quickly breaking out in the NW gate ahead of the line and just outside the SW gate. These cells formed into one large complex that began training over the western gates. The line of storms to the west decayed somewhat as the cells in the western gates continued to grow. Cell motion varied between these areas with the back line (associated with the front) having a more easterly component. Convection also formed on an outflow boundary and brought heavy rain to the airport for about an hour. Light showers continued to fall for a couple more hours after the heavy rain ceased. The strongest convection then moved through the eastern/northern gates and experienced significant decay. *TCWF: TCWF did a good job considering the enormous amount of growth at the beginning of the mission and significant decay later. Initial 200nm scores were 80/60% and remained near that percentage, or higher, throughout the time of greatest impact. Scores dropped as storms moved east and decayed. TRACON scores started at 85/10%, but the 60 minute scores climbed to 60-70% before eastward motion pushed the cells out of TRACON range. With significant growth ahead of the training cells, the exact timing of level 3 at the airport was not accurate, but scores still remained fairly high. A conversation with the Federal Express (FedEx) ATC coordinator on duty during this mission revealed good benefits for both ITWS and TCWF, even though they had not received the TCWF training yet. The coordinator used the ITWS web page to access the TCWF data. This information was used to help determine where the weather was going to be in 30-60 minutes and advise aircraft of what to expect as they approached MEM.*
MEM	18-May-00	2207-1607	An approaching cold front brought the chance for strong to severe thunderstorms to the region. Unfortunately, all of the initial activity outside the TRACON decayed as it approached the runways; thus, the airport only experienced light precipitation. A broken line of thunderstorms impacted the northern airways and gates before exiting the TRACON and decaying. Later, weak showers formed in the SW quadrant ahead of a stratiform precipitation region to the W. These cells briefly reached convective status, but decayed to

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