7.9 **DEVELOPING A MOSAICKED GUST FRONT DETECTION ALGORITHM FOR TRACONS WITH MULTIPLE TDWRS ***

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1. INTRODUCTION

Gust front detection is an important Initial Operational Capability (IOC) of the Integrated Terminal Terminal Weather System (ITWS). The Machine Intelligent Gust Front Algorithm (MIGFA) being deployed for ITWS uses multi-dimensional, knowledge-based signal processing techniques to detect and track gust fronts in Terminal Doppler Weather Radar (TDWR) data. Versions of MIGFA have also been developed for the ASR-9 Weather Systems Processor (WSP) (Delanoy and Troxel, 1993) and NEXRAD, and within the past year MIGFA was installed as the primary gust front detection algorithm for operational TDWRs throughout the United States.

Although MIGFA represents a significant improvement over previous automated gust front detection algorithms (Delanoy and Troxel, 1993; Troxel and Delanoy, 1994; Troxel et al., 1996), ongoing real-time prototype operations at the Dallas Fort Worth (DFW) ITWS prototype site have revealed that the IOC gust front detection capability is not always optimal. Because MIGFA is processing data from a single Doppler radar, one of the principal gust front signatures—radial velocity convergence—often vanishes as fronts propagate over the radar site and become radially aligned. Attempts to mitigate this problem through additional image processing (e.g., addition of an azimuthal shear detector) have helped somewhat, but uninterrupted tracking of gust fronts during overhead passage remains a challenge.

At large TRACON ITWS sites covered by more than one TDWR (e.g., New York, Chicago, Dallas), a separate gust front product mapping algorithm is responsible for producing a single TRACON-wide map of gust fronts detected from each of the TDWRs in the TRACON area. The ITWS gust front TRACON map algorithm (GFTMAP) uses a set of rules to decide which radar's gust front detections are displayed on the ITWS Situation Display (SD). This product-level fusion approach has been problematic, as it is difficult to pre-determine which radar will have the best viewing angle of any specific gust front. This approach has led to fragmented and confusing representations of gust fronts on the ITWS SDs at DFW.

* This work was sponsored by the Federal Aviation Administration under Air Force Contract No. F19628-95-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the U.S. Government. Corresponding author address: Justin D Shaw, Massachusetts Institute of Technology, Lincoln Laboratory, 244 Wood Street, Lexington, MA 02420-9185; e-mail: jdshaw@ll.mit.edu

This paper will describe the problems observed with the MIGFAs operating on data acquired from the two TDWRs at DFW, as well as the problems associated with the current gust front mapping algorithm. We will then outline the strategy being used to create a Gust Front Mosaic algorithm that would replace the current GFTMAP algorithm. Implementation and initial results of the algorithm will be discussed.

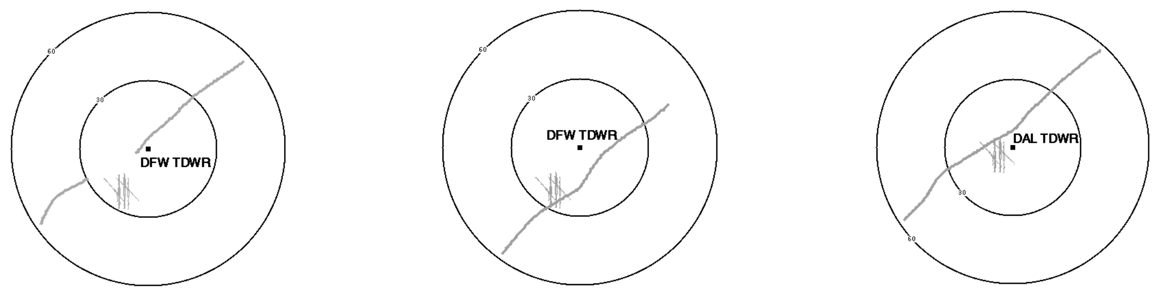
2. THE GUST FRONT DETECTION PROBLEM AT DFW

Within the DFW TRACON, there are two TDWR radars. One provides wind shear information for the DFW airport (DFW) and the other for the Dallas Love airport (DAL). Of the four current ITWS prototype sites (New York, NY; Memphis, TN; Orlando, FL; and Dallas, TX), the DFW ITWS is currently the only one that receives base data from more then one TDWR. However, there will be a number of production ITWS systems deployed in TRACONs where more than one TDWR will be available.

It has been observed by DFW site staff during operations over the last four years that gust fronts with specific orientations tend to have a degraded detection probability from the DFW-based MIGFA. Figure 1 is an example of such a scenario. Figure 1(a) shows a gust front detection from the DFW TDWR, while Figure 1(b) shows the same detection after the front had tracked south of the DFW airport. Notice that there is a large portion of the front missed in Figure 1(a). Notice also that the area that was missed in Figure 1(a) is very close to the DFW airport.

The relatively large number of dropped detections and reduced detection length over the DFW airport by the DFW MIGFA is in large part a consequence of the location of the DFW TDWR with respect to the DFW airport. Most cold fronts (and associated gust fronts) track through the region from the northwest, as in the example of Figure 1. Because the DFW TDWR is sited 17 km NNE of the DFW airport, when a typical SW-NE oriented front crosses the DFW TDWR site, it becomes radially aligned with respect to the TDWR, and the velocity convergence signature is no longer evident in the radar data. Unless the gust front is accompanied by other non-velocity signatures (such as a reflectivity thin line), it is likely to be dropped by the current algorithm.

By contrast, it has been observed that the DAL TDWR will, in most cases, maintain the detection of a gust front as it crosses the DFW airport. The DAL TDWR is located just east of the DFW airport and thus has a better view of a front approaching from the northwest. Figure 1(c) shows the detection of the same front at nearly the same time as Figure 1(a). Because the front has not yet become radially aligned, the DAL TDWR still has a complete detection over the airport. For this reason, the product–level fusion algorithm (GFTMAP) has been configured to use the DAL-based MIGFA detections over nearly the entire TRACON coverage region.



(a) (b) (c)

Figure 1. Gust front detections from the DFW and DAL TDWRs on April 4, 1999. The broken gray line extending from lower left to upper right in (a) is the gust front detection produced by the DFW MIGFA while the gust front was radially aligned with that radar. (b) The same gust front after being re-detected by the DFW MIGFA. (c) Gust front detection from DAL radar corresponding to time of DFW MIGFA detection shown in (a). Range rings are plotted at 30 and 60 km. Figures are centered on the radar, and relative locations of the DFW airport runways are shown.

A study of gust front events that impacted the DFW airport ARENAS (Areas Noted for Attention) was conducted to ascertain the degree of detection degradation with the DFW-based MIGFA. For this study, 52 DFW gust front events were examined between May 21 and November 10, 1998. All detected fronts that impacted the DFW ARENAS, regardless of orientation, were examined. The majority of the fronts were oriented from northeast to southwest such that they would be azimuthally aligned to the DFW TDWR as they impacted the DFW ARENAS. The study found that 21 of the 52 fronts initially detected by the DFW MIGFA were dropped or had reduced detection length such that there were no indications of airport impact on the Situation Display (SD). MIGFA detections from the DAL TDWR were then examined for the same 52 events. It was discovered that the DAL MIGFA held detections for 10 of the 21 fronts that were dropped by the DFW MIGFA. It was also discovered that an additional four of the 21 degraded front detections would have had an improved detection length from the DAL MIGFA, but not a continuous impact of all affected DFW ARENAS. The study concluded that more then half of the degraded DFW MIGFA detections would have been improved to a point that there would have been indications of runway impact, had the DAL and DFW detections been combined in the most optimum manner for the duration of the event.

After the initial study of the DFW gust fronts was completed, the GFTMAP algorithm at DFW was reconfigured to select the DAL-based MIGFA as the source of gust front detections over the DFW ARENAS. This has increased the number of detections for the DFW TRACON. However, additional data collected over the last two years have shown that fronts can be oriented in such a way that the DAL MIGFA will drop detections over the DFW ARENAS, so it is not always the radar of choice for all gust front geometries.

The complex dependency of MIGFA detection capability on gust front location and orientation cannot be adequately represented by the pre-determined rule base used by the current product-level fusion algorithm (GFTMAP) to determine which radar's gust front product to display. Each MIGFA has already applied a threshold to its combined interest image without the benefit of evidence seen by the other radar. Too much information has been lost by the time the GFTMAP algorithm tries to perform its mosaic. Fusing the gust front evidence from the two radars prior to gust front extraction (thresholding) would increase the probability of maintaining detections of gust fronts, regardless of their orientation as they pass over the DFW airport.

3. MIGFA INTEREST IMAGES

To identify gust fronts in radar imagery, MIGFA runs a series of independent feature detectors that look for various Doppler radar signatures indicative of gust fronts (e.g., reflectivity thin lines, radial velocity convergence). The feature detectors employ a generalized pattern-matching technique developed at Lincoln Laboratory called Functional Template Correlation (FTC), which through the use of scoring functions (as opposed to flat thresholds) incorporates aspects of fuzzy set theory (Delanoy, et al., 1992). The output of FTC is a pixel-map of probabilities that the particular feature is present—or not present—in the imagery. The resulting evidence maps are referred to as "interest images" and provide a mechanism for data fusion. Using relatively simple rules of combination (e.g., confidence-weighted averaging), evidence embodied in the individual interest images is combined to produce a consensus on the presence or absence of gust fronts. The combined interest image represents the assimilation of all the evidence seen by that radar and is the basis for subsequent gust front feature extraction by MIGFA.

The combined interest image is not typically part of the standard algorithm product output. However, the Lincoln prototype software provides a mechanism for outputting the images computed during processing on the product output stream. We are using this capability to explore real-time mosaicking of MIGFA interest images.

4. GUST FRONT MOSAIC STRATEGY

Two goals of this study were deemed important in determining an appropriate strategy for creating a mosaicked gust front product. The first was to decrease the number of missed detections and improve the quality of low percent length detected gust fronts due to radial alignment. The second was to reduce the number of false detections produced by a single MIGFA. Our strategy was to create a mosaic of the interest fields generated by each individual algorithm and identify gust fronts within the interest mosaic. Observations of MIGFA's performance at the Dallas ITWS field site have revealed a tendency for false detections to occur with greater frequency as the distance from the TDWR increases. This occurs because conditions responsible for invalid detections, such as strong vertical wind shear and data void regions due to second trip editing, are typically not located near the radar site. Using this information, a scheme was devised to combine interest fields that are the output of individual MIGFA processes running on single TDWRs.

The initial step in creating the gust front mosaic product was to establish a new Cartesian domain large enough to encompass all of the MIGFA interest data from each of the TDWRs located inside the TRACON. The center of the new combined TRACON domain was arbitrarily chosen near the midpoint of the two radars, and the mosaic Cartesian grid resolution was kept the same as that of the input MIGFA interest images (500 m). Figure 2 illustrates the domain for the DFW TRACON and the locations of the DFW and DAL airports and TDWRs.

Next, the combined interest fields generated by each individual MIGFA were mapped into the TRACON domain by translating the interest values by the relative offsets of each radar with respect to the center of the TRACON domain. A mosaic output grid the size of the TRACON domain was then established to receive the mosaic interest values. The interest values assigned to each mosaic grid point were computed using a set of rules that were applied to the interest image values from each of the individual MIGFAs.

The rules currently used to determine the value at each point in the mosaic interest field are relatively simple. Figures 3(a) and 3(b) show the locations of the DFW and DAL airports in relation to the TDWR that monitors each airport. The dark shaded region in each figure is the Radius of High Confidence (RHC). This is the area within 30 km of the radar that contains the airport runways and is the area in which gust front false alarm probability is lowest. Following the remapping of the individual MIGFA interest images onto the TRACON domain, the mosaic combination logic consists of taking the maximum of all interest values that fall into the same TRACON domain grid cell. Before being tested as a maximum value, each interest value is first checked to see where it lies with respect to the RHC for that radar. If it is within the RHC, it is tested immediately. If it is outside of the RHC, then the interest value is first averaged with corresponding original interest values from the other images before being tested as the maximum interest for that location. This reduces the likelihood that high interest values from a single radar's lower confidence area will trigger a false detection from the resulting mosaic. The final mosaic interest field is then used as the basis for gust front extraction.

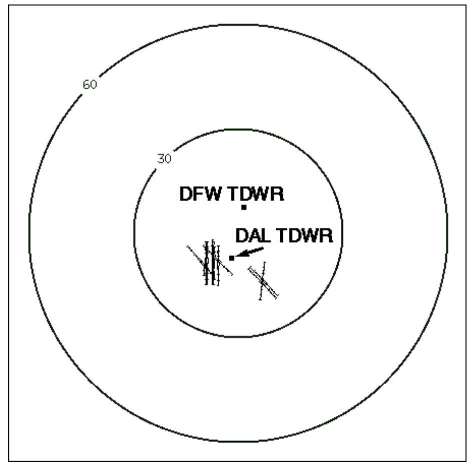
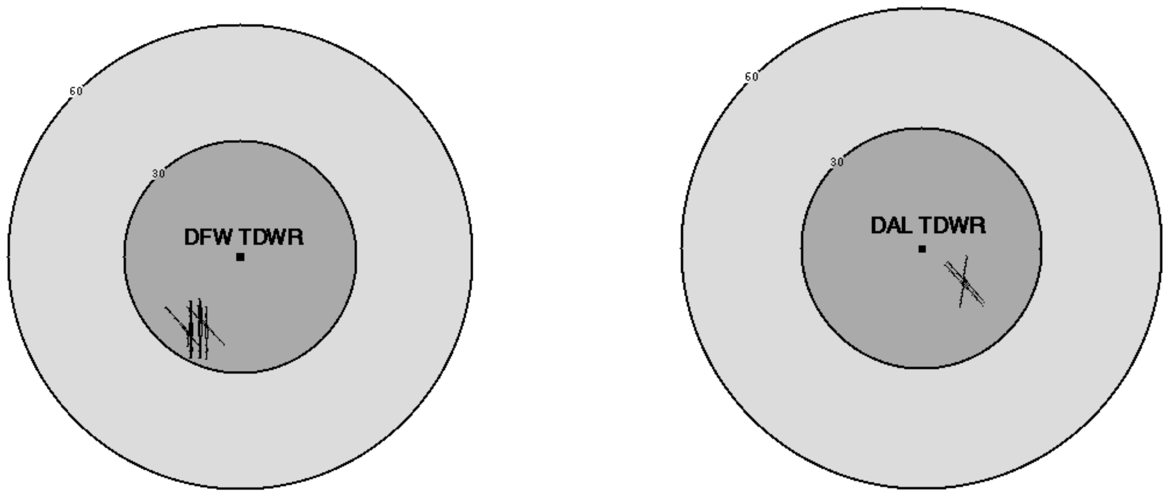


Figure 2. TRACON domain created to encompass data from the DFW TDWR and the DAL TDWR. The line figures near the center of the image are the DFW and DAL runways, respectively. Range rings are plotted at 30 km intervals. The center of the TRACON domain is the midpoint between the two TDWR radars.

5. IMPLEMENTATION/PRELIMINARY RESULTS

Figure 4 is a flowchart illustrating how the Gust Front Mosaic algorithm would fit into the existing ITWS gust front product generation string. Individual MIGFAs would continue to operate as they currently do. That is, they would continue to ingest data from a single TDWR and identify areas of gust front interest. The output from the individual MIGFAs would be expanded to include the interest images that would be the input for the Gust Front Mosaic algorithm. The Gust Front Mosaic algorithm would mosaic the individual interest images, perform gust front extraction and wind analyses, and send the resulting gust front detections and forecasts to an expanded-coverage Gust Front Update (GFUP) algorithm that controls product delivery to the Situation Display (SD). A major consideration in developing the mosaicked algorithm was to reduce the complexity of implementing the new product within the IOC ITWS framework. Significant portions of MIGFA functionality need to be replicated inside the Gust Front Mosaic algorithm (chain extraction, wind analysis, reporting heuristics). The software is being designed such that the replicated functionality can be implemented with few modifications to the original MIGFA routines, thereby minimizing future technology transfer costs.



(a) (b)

Figure 3. Coverage area for the (a) DFW TDWR and the (b) DAL TDWR. Locations inside the Radius of High Confidence (RHC) have dark shading while locations outside the RHC have light shading. The line figures in each image are the DFW and DAL runways, respectively.

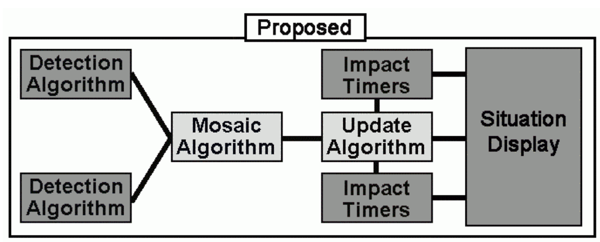


Figure 4. Proposed framework for the new gust front mosaic product. The dark shaded blocks are systems that are not modified. Light shading indicates new or modified algorithms.

The method of data fusion described in this paper has been implemented and some initial data have been analyzed. The results from one DFW case that occurred on April 23, 1999 have been encouraging. Figure 5 shows the gust front detection from the mosaicked product for the same case as Figure 1(a). Notice how the detection across the DFW airport is maintained. Further analyses are needed, and the algorithm will likely be refined as more experience with additional cases is gained. A test suite of DFW gust front cases is being assembled to assess the mosaic approach. The majority of these cases have detectable gust fronts that were dropped by the DFW-based MIGFA due to their alignment in relation to a TDWR. Results from these cases will be compared against results from the individual MIGFAs to ensure that no degradation of the original MIGFA product has been created by the Gust Front Mosaic algorithm.

6. SUMMARY

The difficulty of the MIGFA algorithm in maintaining gust front detections due to radial alignment with the radar is a recognized limitation. The problem is especially acute at the DFW airport because of the location of the DFW TDWR. A study of 52 cases from 1998 showed that over 1/3 of all gust fronts became radially aligned with the DFW TDWR as they crossed the DFW runways, resulting in lost or degraded detections by the DFW-based MIGFA. The same algorithm, using data from the DAL TDWR, was successful in maintaining a gust front detection over the DFW runways in many of the cases that the DFW MIGFA dropped. Results of the study suggest that combining the evidence from both radars prior to gust front extraction would create a superior product. Furthermore, producing a single TRACON map of gust front detections from the fused interest images obviates the need for the current product-level fusion approach, which has been observed to have significant limitations.

Work is continuing on refining the data fusion techniques described herein, along with the subsequent gust front feature extraction and wind analysis that comprise the complete gust front product generation. Several challenges remain, but the initial results confirm the feasibility of the selected approach. Future work will include running the Gust Front Mosaic algorithm on the entire test case suite and off-line monitoring of its performance during real-time operations at the DFW ITWS field site.

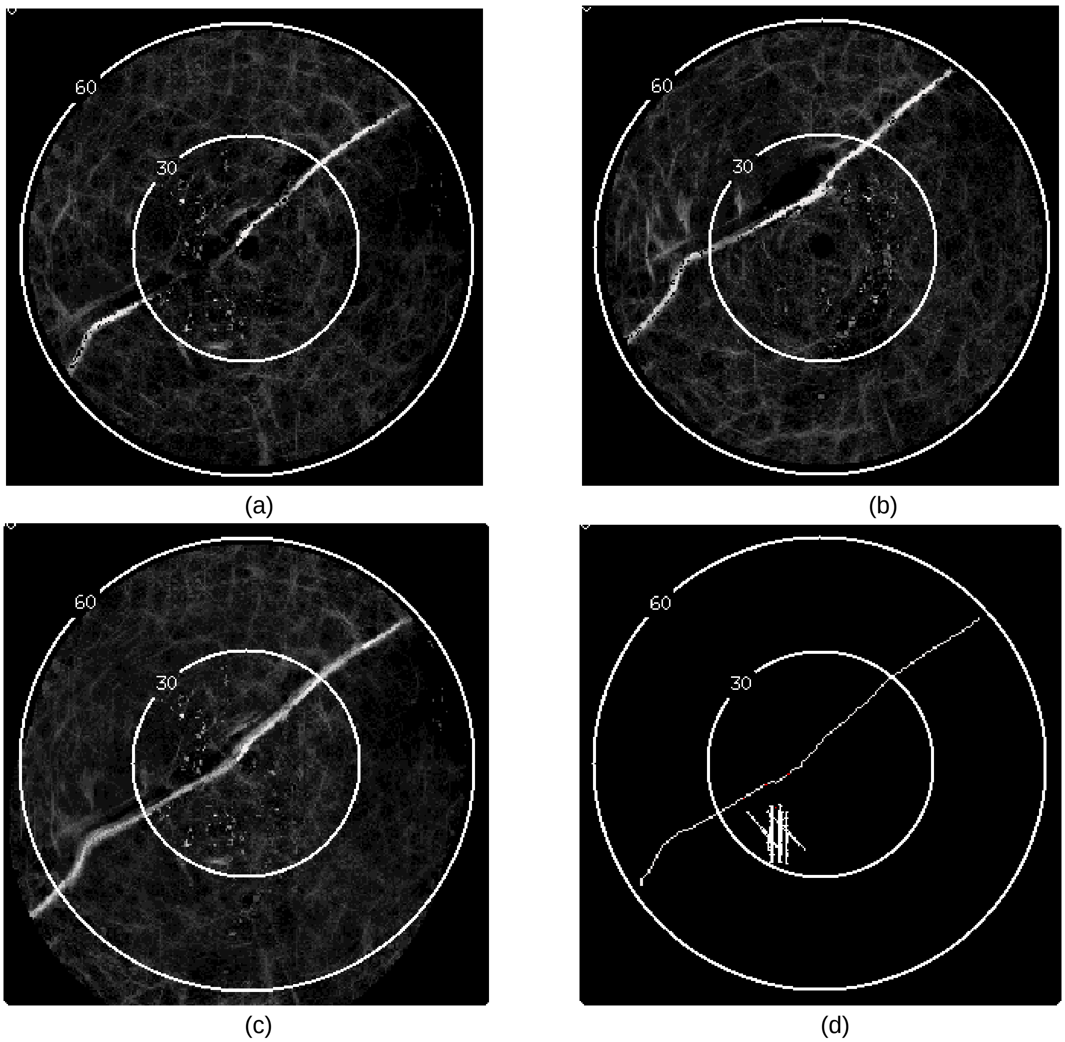


Figure 5. Example of a gust front detection generated from a mosaicked interest field for the same time and case as displayed in Figure 1. The individual interest images from the DFW MIGFA (a) and the DAL MIGFA (b) are shown, as well as the mosaicked interest image (c) and the resulting detection (d). Interest values in (a), (b), and (c) are displayed using a gray scale, with white representing confirming interest and black representing disconfirming interest. Comparing (d) to Figure 1(a) shows the advantage of using the mosaicked interest as the basis for gust front detection. The range rings in all images are centered on the TRACON grid center point with rings at 30 and 60 nm. The DFW runways are plotted in (d).

7. REFERENCES

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