JP1.32 AN EVALUATION OF THE MEDIUM-INTENSITY AIRPORT WEATHER SYSTEM (MIAWS) PRODUCTS AT THE MEMPHIS, TN AND JACKSON, MS INTERNATIONAL AIRPORTS

Mark A. Isaminger* and Erik A. Proseus
MIT Lincoln Laboratory, Lexington, Massachusetts

1. INTRODUCTION[†]

The FAA is procuring aviation weather systems, which are designed to enhance safety/capacity and reduce delays at U.S. airports (Evans and Weber, 2000). The two most widely publicized systems currently being installed are the Integrated Terminal Weather System (ITWS) at airports equipped with a Terminal Doppler Weather Radar (TDWR) and the Weather System Processor (WSP) at those terminal areas covered by an Airport Surveillance Radar (Cole and Kelley, 1996), Model 9 (ASR-9). At airports not slated to receive either an ITWS or WSP, an emerging system coined the Medium-Intensity Airport Weather System (MIAWS) will be installed (Rappa et al, 2000). Currently, either an ASR-7 or 8 provides terminal aircraft surveillance at these airports. Unfortunately, these platforms do not output calibrated precipitation intensity or storm motion information. Quantitative six-level weather reflectivity data will be available once the digitally enhanced ASR-11 radar system is operational at MIAWS supported sites. The Low Level Wind Shear Alert System - Relocation/Sustainment (LLWAS-RS) anemometer network (Nilsen et al, 1999) will provide MIAWS with surface-based winds and wind shear alerts.

The rationale for MIAWS evolved from the ITWS and WSP prototype testing. The premise is that the calibrated reflectivity and velocity data from start-of-the-art radar platforms can be utilized to produce a suite of current and forecasted storm positions to aid air traffic control decision making (Evans and Weber, 2000). The forecasted location is a critical issue if the storms are moving rapidly. This can lead to a scenario where the weather conditions deteriorate significantly within a matter of minutes. Once implemented, MIAWS will be an essential component of the National Airspace System by providing this evolving technology to airports whose traffic counts are not sufficient to warrant either an ITWS or WSP, but where commercial carriers could reap the benefits of a high-quality weather radar system.

The FAA has contracted the Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL) to undertake a proof-of-concept evaluation of MIAWS. To this end, MIT/LL installed two prototype systems at the Jackson, MS (JAN) and Memphis, TN (MEM) International Airports. The system at MEM is used solely for product evaluation and refinement, while the FAA is operationally evaluating the JAN MIAWS. The focus of this report is a preliminary assessment of the capabilities and limitations of MIAWS in its current implementation, i.e. precipitation based solely on NEXRAD data. Potential enhancements to the NEXRAD product data and MIAWS algorithms will also be discussed.

2. PRODUCT DESCRIPTION

The products evaluated herein are six-level precipitation, storm motion/extrapolated position, and precipitation impacts. The primary NEXRAD product used by MIAWS is the 1-km maximum composite reflectivity. In order to mitigate anomalous propagation (AP) in the 1-km data, the 4-km maximum composite AP-edited product is also used.

2.1 Precipitation

The NEXRAD composite reflectivity product is the maximum reflectivity at any elevation tilt for each 1 km x 1km Cartesian bin. The data is quantified into 5 dBz reflectivity bins and then converted to Video Integrated Processor (VIP) levels. Once the data has been converted to VIP, the 4-km product is used to discriminate weather from AP in the higher resolution grid.

Since the NEXRAD volume scan rate is only 5-6 minutes in precipitation or severe weather mode, latency is a key issue with this product. Thus, the precipitation data is advected every 30 seconds based on the gridded motion vectors. The latency value is also reported on the Situation Display (SD) to inform the Users how much time has passed since the volume data were collected. The data are displayed to a range of 100 NM, which is more than sufficient for smaller airports.

2.2 Storm Motion/Extrapolated Position

The motion estimates are based on an image-processing technique that compares two precipitation maps, which are separated in time (Chornoboy et al., 1994). The tracker divides the radar image into overlapping regions and then correlates the echoes between successive volume scans to find the displacement that provides the best match. For each subimage, this process yields a motion vector. Next, a grid is constructed and the motion vectors are smoothed and associated to nearby cells. For this product, all of the vectors associated with level 3+ storm cells are displayed. The update rate is 30 seconds to match the advection rate of the precipitation product. The storm extrapolated position contours serve as a supplemental product to the motion vectors. They provide an indication of the storm's leading edge, along with the projected location 10 and 20 minutes. They represent pure advection and do not explicitly capture growth or decay.

2.3 Precipitation Impacts

The precipitation impacts are based on the same methodology used to generate wind shear or microburst alerts by a TDWR, WSP, or ITWS (Klingle-Wilson, 1995). Basically, the warning region encompasses the runways, as well as the approach and departure corridors (1-NM boxes), which extend out to 3 or 2 NM, respectively. There is also a 0.5 NM buffer on either side of the runway or extended centerline to account for advection latency and growth/decay. For this approach, the rudimentary cell shapes created by the storm motion algorithm

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*Corresponding author address: Mark Isaminger, MIT Lincoln Laboratory, 244 Wood Street, Lexington, MA 02420-9108; e-mail: marki@ll.mit.edu

are used to determine impacts. If a cell shape overlaps a warning box, then the number of moderate (level 3 and 4) and heavy (level 5 and 6) pixels within the box is tabulated. The current software requires at least three pixels above a given intensity level to generate a precipitation impact message. Using cell shapes to determine whether to send an alert rather than individual pixels, allows the impact processor to be more accurate by reducing noise-induced false alerts.

3. NEXRAD DATA QUALITY ISSUES

The most common NEXRAD DQ problem is AP. This type of degradation is even more troublesome if the weather and AP are co-located. It is essential that the radar data be cleaned up as much as possible via either front-end signal processing or an algorithmic editing technique (Isaminger et al., 1997). The other DQ issues examined here are bright-band contamination, NEXRAD product degradation, radar calibration issues, cone of silence, and test data.

3.1 Anomalous Propagation

In order to suppres ground clutter, the NEXRAD first uses a series of high pass clutter filters capable of eliminating stationary targets with intensities as high as 45 dB. On many radars, the filters are disabled or the least-mitigating filter is chosen, so as not to corrupt the rainfall estimates used for hydrological purposes. This in turn can result in significant clutter breakthrough around the radar site, as well as AP returns when conditions are favorable. If this situation is left unchecked, it can seriously degrade the quality of the base/product data. An editing algorithm is required to clean up the data, without significantly contaminating the hydrological estimates.

The algorithm currently running in the NEXRAD system is modeled after a technique developed and tested by MIT/LL at the ITWS prototypes (Isaminger et al., 1997). It first attempts to discriminate AP from weather or clear-air returns based on using reflectivity/velocity/spectrum width thresholds at the base data level. After a range gate has been flagged as AP, continuity constraints are used to extend the identification technique across data sparse regions. Finally, the algorithm uses a filter to try and remove speckles of AP residue. The NEXRAD technique uses a median filter, which unfortunately magnifies the region of AP breakthrough. Another limiting factor is that the velocity and spectrum width tests are applied at the product resolution (1-km) versus the base data resolution (0.25-km). In a similar fashion, the quantization of the velocity/spectrum width values to 1 m/s intervals is also an issue.

Ever since the initial MIAWS system was installed at MEM in the summer of 2000, the most persistent and significant DQ issue has been AP (Figure 1). In this case on 000714, there are widespread areas of AP in all quadrants due to the lack of clutter filtering or polygon editing. The larger regions of AP breakthrough have motion vectors and extrapolation contours, which compounds the problem in terms of quickly identifying the validity of the returns. Significant AP (level 2 or greater) was documented on 136 test days, i.e. 71 percent.

3.2 Cone of Silence

Due to the nature of the scan strategy and/or beam coverage, each radar has a region in close proximity to the site where the precipitation returns can be missed or underestimated if the cell is developing aloft. This problem is especially troublesome if the radar is located near the runways, such as at JAN.

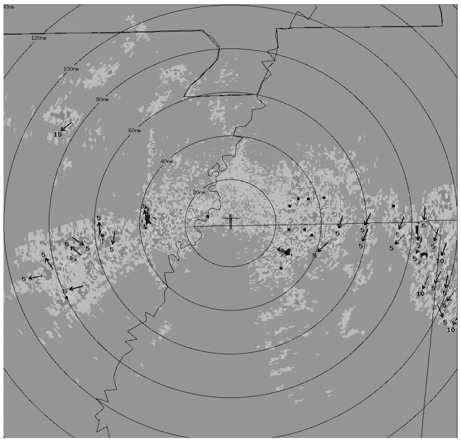
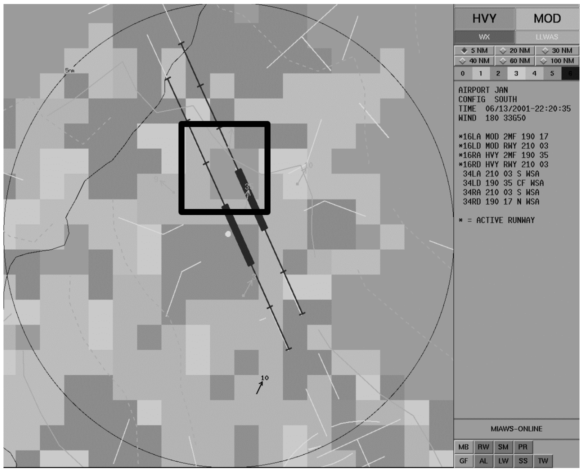


Figure 1. An image from MEM showing widespread AP contamination.

An example of the loss of precipitation data within the cone of silence is shown in Figure 2. In this case, there are no precipitation returns centered on the end of Runway 16LA (black box). The NEXRAD location is actually farther south, but the advection technique has shifted the missing data region to the north. Notice how there are precipitation impacts messages on all of the active runways, even with the data void. In this example, the precipitation domain is quite large and encompasses the cone of silence. The concern is that an isolated cell, in the developing phase, might be missed entirely near the radar site. During real time operations, the JAN MIAWS display was scrutinized virtually every time weather impacted the airport to determine the frequency of this problem. There were never any cases noted where the cone of silence completely masked the cell and caused no impact message to be issued. Thus, the probability of this occurring is quite low. The main issue with the cone of silence would be improperly identifying the first encounter location of a cell.



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AIRPORT JAN
CONFIG  SOUTH
TIME  06/13/2001-22:20:35
WIND  180 33G50

*16LA MOD 2MF 190 17
*16LD MOD RWY 210 03
*16RA HVY 2MF 190 35
*16RD HVY RWY 210 03
 34LA 210 03 S WSA
 34LD 190 35 CF WSA
 34RA 210 03 S WSA
 34RD 190 17 N WSA

* = ACTIVE RUNWAY
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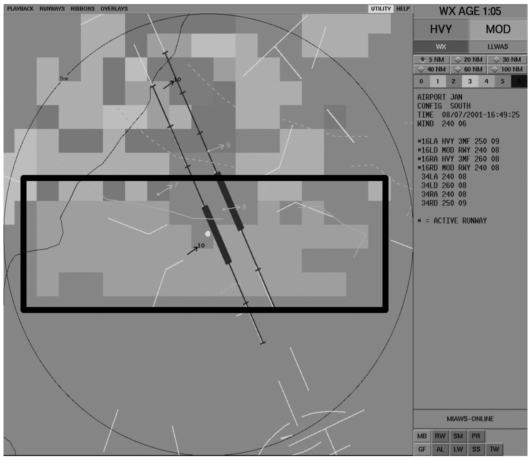
Figure 2. An image from JAN showing a precipitation data void within the cone of silence.

3.3 Other Data Quality Issues

The other DQ issues evaluated during the demonstration were NEXRAD composite product degradation, bright band contamination, radar calibration problem, and test data. The last two occurred very infrequently and will not be discussed herein. Events categorized as NEXRAD product degradation occurred when the AP-editing median filter technique caused small amounts of noisy data to be expanded into blocks of erroneous precipitation returns. This type of degradation was considered significant since it could lead to false precipitation impacts within the area of concern. An example of this problem is shown in Figure 3. In this case, there is a rectangular block of level 4 returns that extends from west-to-east across the center of the image. The data contamination intersects 16LD/16RD and is causing precipitation impact messages, even though the weather cell in this case is located along the approach corridor.



```
AIRPORT JAN
CONFIG  SOUTH
TIME  08/07/2001-16:49:25
WIND  240 06

*16LA HVY 3MF 250 09
*16LD MOD RWY 240 08
*16RA HVY 3MF 260 08
*16RD MOD RWY 240 08
 34LA 240 08
 34LD 260 08
 34RA 240 08
 34RD 250 09

* = ACTIVE RUNWAY
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Figure 3. An image from JAN showing the AP-editing median filter product degradation.

Due to the nature of the composite product i.e. maximum value, bright band contamination is possible whenever the precipitation is stratiform in nature such as during the cold season. In this case, the precipitation returns near the freezing level are enhanced due to the change from a liquid to a solid state. The maximum composite product would then show a band of higher returns within the stratiform regime that would not be accurate in terms of the precipitation severity. An example of this problem from JAN is shown in Figure 4. In this case, the radar is located on the airport, near the center of the image. The general precipitation pattern is stratiform. The concentric rings of higher values around the airport occur where the conical tilt volumes intersect the altitude at which the precipitation is changing state hear the freezing level.

4. PRODUCT EVALUATION

The main focus of this report is to evaluate the performance of the MIAWS product suite. As has been discussed previously, the capabilities and limitations of the products are closely tied to the NEXRAD DQ, which is by far the most important factor in determining product limitations in the current operating state.

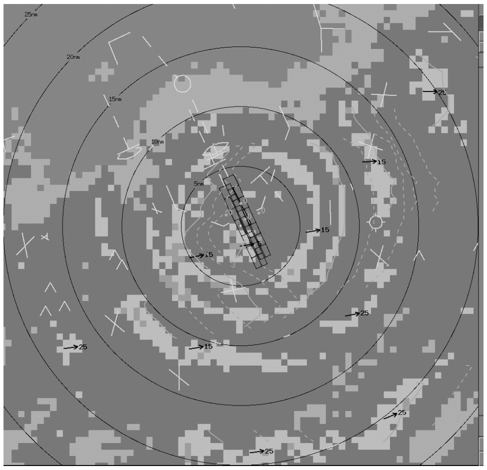


Figure 4. An image from JAN showing bright band contamination.

4.1 Precipitation

One of the most obvious limitations of the NEXRAD composite precipitation data is latency. While the data is advected to give a better indication of the storm location, the intensity can be radically different than displayed due to cell growth and decay. DQ issues can also contaminate this product, as shown in the previous section. Without a doubt, the most significant problem with the six-level weather data is degradation caused by AP. Another facet of the composite product is that the precipitation estimates are, in some cases, more indicative of the storm structure aloft than at the surface. Overall, the NEXRAD composite precipitation product is deemed reliable as long as the most significant DQ degradation issues can be mitigated.

4.2 Storm Motion/Extrapolated Position

The ITWS/MIAWS storm tracker has been shown to do a credible job in terms of advecting the weather as long as the cells are not quasi-stationary (Klingle-Wilson, 1995). However, this analysis was based on the ASR-9 product, which has a latency of only 30 seconds. It is unclear how much of an impact the slower NEXRAD update rate would have on the performance metrics documented by Klingle-Wilson. What is clear is that the primary algorithm deficiencies occur when the storms are slow moving, growing/decaying, limited in areal coverage, or near the edge of the detection region. According to the MIAWS operations logs, storm vector problems such as these were recorded on 15 percent (20/132) of the weather days. The frequency of occurrence on a storm-by-storm basis would be much less.

The combined aspects of slow motion and growth/decay on the tracker product are shown in Figure 5, a case from JAN during a period with weak steering flow. The net result is storms that essentially grow and decay in place. An inspection of the vectors shows significant motion variability. If the cell in question is in close proximity to the airport, it could lead to uncertainty in terms of whether the runways would be impacted.

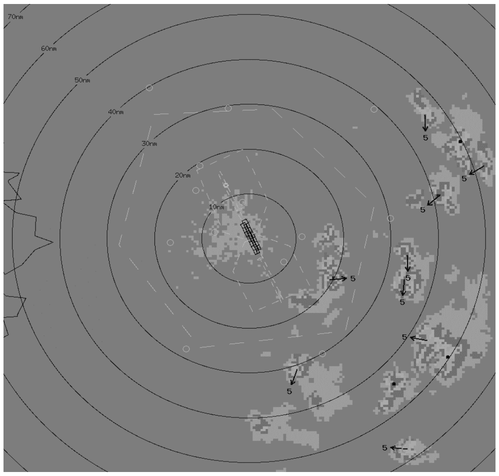


Figure 5. An image from JAN showing the variability in storm motion when the cells are stationary or slow moving.

One of the key aspects of establishing a MIAWS site at MEM was to compare the MIAWS products to the NEXRAD-based ITWS products. This has been quite advantageous for both the precipitation and motion product evaluations. For the most part, the ITWS and MIAWS storm tracking information are in good agreement, especially if the storms are widespread and moving at least 10 kts. Slow-moving storms are more troublesome. A case from MEM on 000822 is used to illustrate this point. The ITWS motion vectors are shown in Figure 6a, while Figure 6b displays the MIAWS vectors for the same time period. As shown by ITWS, the cells are either stationary or moving slowly east. On the other hand, the MIAWS vectors are erratic and show the storms moving in different directions. Growth and decay is clearly influencing the MIAWS vectors more than ITWS. This type of disparity was puzzling since both products are based on essentially the same input data and resolution. Modifying the site adaptable parameters to more closely match those used by ITWS rectified the problem. There are still minor tracking disparities between ITWS and MIAWS, but these are expected based on the fact that the input precipitation maps are not identical. Further improvements can be realized by including the Terminal Convective Weather Forecast Product, which is designed to focus on growth and decay and envelope motion (Wolfson et al, 1999).

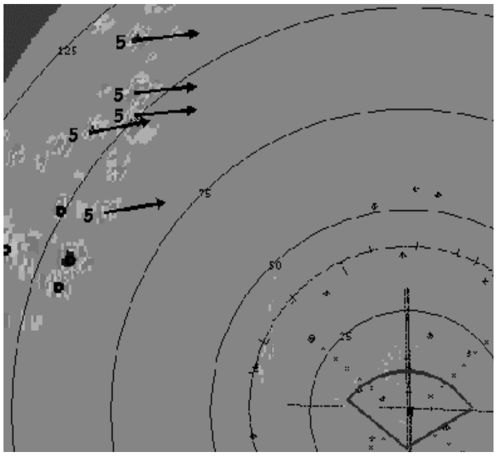


Figure 6a. An image from MEM showing the ITWS 100-NM storm motion vectors on 000822.

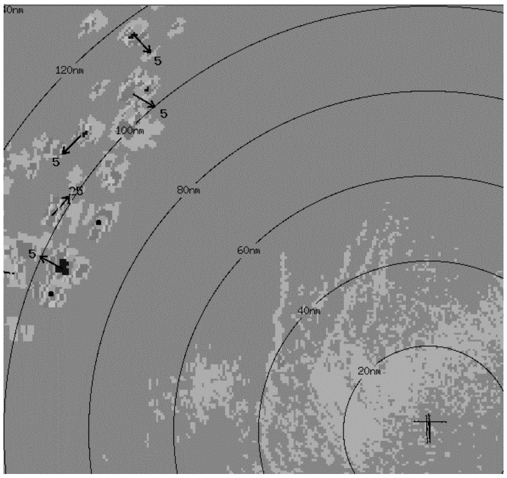
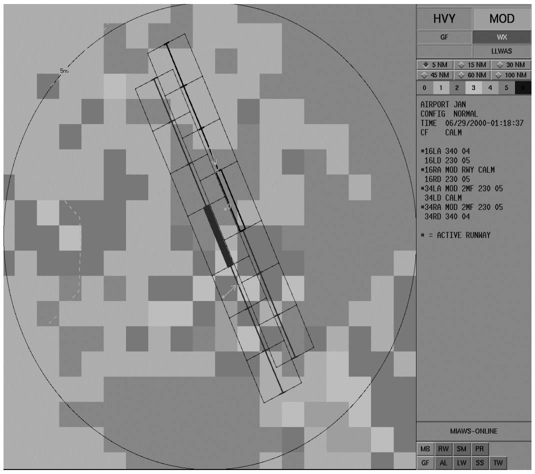


Figure 6b. An image from MEM showing the MIAWS storm motion vectors on 000822.

4.3 Precipitation Impacts

Using the precipitation data to generate impact-warning messages is a novel technique that is unique to MIAWS. During the testing phase, there were significant problems noted with the original impact alert processing technique. The basic problem with this approach was that individual precipitation pixels were tested to determine an impact. The technique was flawed in that noisy data could cause erroneous impact messages. Another problem was that the resolution of the cells is similar to that of the warning boxes. The result was a significant number of precipitation impacts that were deemed false, as well as valid impacts that went unreported. An example of this scenario is shown in Figure 7. In this case, the majority of the level 3 and greater precipitation is located along the southbound departure corridors. There is also an impact message on the arrival end of 16R due to one level 3 pixel overlapping the runway. Since the modified rule-set calls for at least three pixels to generate an impact, this alert would be deemed false. Using the storm cell shapes rectified impact disparities like this one.



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AIRPORT JAN
CONFIG  NORMAL
TIME  06/29/2000-01:18:37
CF    CALM

*16LA 340 04
 16LD 230 05
*16RA MOD RWY CALM
 16RD 230 05
*34LA MOD 2MF 230 05
 34LD CALM
*34RA MOD 2MF 230 05
 34RD 340 04

* = ACTIVE RUNWAY
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Figure 7. An image from JAN showing the precipitation impacts on 000629.

5. SUMMARY/RECOMMENDATIONS

This paper has described the capabilities and limitations of the MIAWS products using only NEXRAD data. It is clear from this investigation that the product validity is closely related to the quality of the data. By far, the removal of AP is the most important enhancement needed to allow MIAWS products to achieve their optimum performance. Addressing the issue at the front-end processing level appears to offer the best hope of mitigating contamination. The other DQ issues of significance to MIAWS are NEXRAD product degradation and precipitation loss within the cone of silence.

The main focus of this analysis was to address the product shortcomings and recommend areas for potential improvement. Overall, the products were deemed useful in a qualitative sense and most failure modes could be traced to inadequacies in the input data or adaptable parameters. Many of the challenges faced by MIAWS are similar to those being addressed by other NEXRAD-based aviation weather systems. The mitigation of AP at the base data level should be the highest priority item. This effort will involve close interaction between the FAA, NWS, and the research community to ensure the entire User requirements are satisfied with respect to the composite/layered products. Researchers at MIT/LL are currently quantifying the impact of several AP-related site adaptable parameter changes on the 1-km composite product.

Another area for improvement involves the precipitation impacts. This product could be enhanced by modifications to either the NEXRAD AP-editing technique or the MIAWS algorithm. The quantitative impact of DQ issues and algorithm shortcomings should be assessed first. This would involve determining the validity of the impacts based on, for example, the one-minute TDWR surface precipitation map as truth. This undertaking will eliminate any time periods with significant TDWR attenuation so as not to bias the results.

Finally, many of the techniques used in ITWS can be incorporated into the MIAWS program as well. For one, ITWS is using a 1-km resolution Vertically Integrated Liquid Water (VIL) product to generate the precipitation forecasts (Wolfson et al., 1999). As shown by Crowe and Miller (1999), VIL is an excellent indicator of storm severity and also serves to clean up some of the radar data quality concerns. MIT/LL will be testing the 1-km VIL product in the near future to assess the impact on data quality degradation. Another area for improvement is to mosaic the data from several sensors to offset the limitations created by using one sensor. For MIAWS, the plan is to merge the NEXRAD and ASR-11 data into one precipitation product. MIT/LL is currently testing different mosaicing techniques in order to create the most viable product. These two upgrades should help to solve many of the precipitation impact disparities noted during this analysis.

6. REFERENCES

Chornoboy, E.S., A.M. Matlin and J.P. Morgan, 1994: “Automated Storm Tracking for Terminal Air Traffic Control,” Massachusetts Institute of Technology Lincoln Laboratory, Lexington, MA, The Lincoln Laboratory Journal, Vol. **7**, No.2, 475-502.

Cole, E. Lee and P.J. Kelley, 1996: “Implementation of the WSP on ASR Radar’s”, *Workshop on Wind Shear and Wind Shear Alert Systems, Amer. Meteor. Soc.,* Oklahoma City, OK., pp. 103-109.

Crowe, B.A., and D.W. Miller, 1999: “The Benefits of Using NEXRAD Vertically Integrated Liquid Water as an Aviation Weather Product,” *Eight Conf. on Aviation, Range, and Aerospace Meteorology,* Amer. Meteor. Soc., Dallas, TX., pp. 244-248.

Evans, J.E., and M.E. Weber, 2000: “Weather Radar Development and Application Programs”, Massachusetts Institute of Technology Lincoln Laboratory, Lexington, MA, *The Lincoln Laboratory Journal,* Vol. 12. No. **2**, 367-380.

Isaminger, M.A., B.C. Crowe, B.G. Boorman, J.E. Evans, and R.A. Boldi, 1997: “Performance Characteristics of an Algorithm to Remove Anomalous Propagation from the NEXRAD Data”, *28th Conf. on Rad. Meteor*., Amer. Meteor. Soc., Austin, TX., pp. 317-319.

Klingle-Wilson, D.L., 1995: “Integrated Terminal Weather System (ITWS) Demonstration and Validation Operational Test and Evaluation”, PROJECT REPORT ATC-234, Massachusetts Institute of Technology – Lincoln Laboratory, Lexington, MA., 103 pp.

Nilsen, J.D., P.A. Biaggi, and F.W. Law, 1999: “ Implementation Status on the Low Level Wind Shear Alert System Relocation and Sustainment Program (LLWAS-RS),” *Eight Conf. on Aviation, Range, and Aerospace Meteorology,* Amer. Meteor. Soc., Dallas, TX., pp. 424-428.

Rappa, Gregory W, Walter Heath, Evelyn Mann, and Anne Matlin, 2000: “Medium Intensity Airport Weather System (MIAWS),” *Ninth Conf. on Aviation, Range, and Aerospace Meteorology,* Amer. Meteor. Soc., Orlando, FL., pp. 122-126.

Souders, Cheryl G, and Robert C. Showalter, 2000: “The Modernization of Federal Aviation Administration (FAA) Weather Systems – An Update,” *Ninth Conf. on Aviation, Range, and Aerospace Meteorology,* Amer. Meteor. Soc., Orlando, FL., pp. 1-6.

Wolfson, M. M., B.E. Forman, R.G. Hallowell, and M.P. Moore, 1999: “The Growth and Decay Storm Tracker,” *Eight Conf. on Aviation, Range, and Aerospace Meteorology,* Amer. Meteor. Soc., Dallas, TX., pp. 58-62.