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ATC-168

ASR-9 Weather Channel Test Report, Executive Summary

S. W. Troxel

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Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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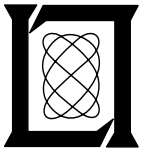

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16. Abstract

The ASR-9, the next generation airport surveillance radar, will be deployed by the FAA at over 100 locations throughout the United States. The system includes a weather channel designed to provide ATC personnel with timely and accurate weather reflectivity information as a supplement to normal aircraft information.

Comparisons between data from an ASR-9 in Huntsville, Alabama, recorded during design qualification and testing, and data from two other "reference" radars, were used as the basis for assessment of ASR-9 weather channel performance. Results suggest that, with the exception of an apparent 3 dB discrepancy between the weather products of the ASR-9 and the "reference" radars, the ASR-9 weather channel seems to perform according to FAA specifications.

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SECTION 1

INTRODUCTION

The ASR-9, the next generation airport surveillance radar, will be deployed by the FAA at over 100 locations throughout the United States. The system includes a weather channel designed to provide ATC personnel with timely and accurate weather reflectivity information as a supplement to normal aircraft information. This report presents results of an assessment of the ASR-9 weather channel performance. Two issues addressed are:

(1) Whether the ASR-9 weather channel performs according to FAA specifications.

(2) Whether the ASR-9 weather channel adequately represents weather reflectivity for ATC purposes.

These assessment results are intended to support the FAA in developing the operational use of ASR-9 weather information.

Comparisons between data from an ASR-9 in Huntsville, Alabama, recorded during design qualification and testing, and data from two other "reference" radars, were used as the basis for the assessment. Several storm cases were analyzed, comprised of stratiform rain, isolated convective storms, squall lines, and cold fronts containing multiple simultaneous convective storms. Results suggest that, with the exception of an apparent 3 dB discrepancy between the ASR-9 and "reference" radar weather products, the ASR-9 weather channel seems to perform according to FAA specifications. Although the ASR-9 products give a reasonable representation of the extent and severity of potentially hazardous weather in Huntsville, the results suggest the static storm model used to determine beamfill corrections for the ASR-9 should be optimized for the particular climatic region in which future ASR-9s will be operated.

The left-hand portion of Figure 1 is a simulated normal video display of weather as seen by current ASRs. These echoes are uncalibrated and non-quantized; no detail or structure can be discerned within the displayed echo pattern. By contrast, the ASR-9 weather channel is capable of producing calibrated reports of weather reflectivity quantized to correspond to the six levels used by the National Weather Service (NWS). These levels are associated with precipitation intensity ranging from light (level 1) to extreme (level 6). The right-hand portion of Figure 1 is a simulated display of weather echoes produced by the weather channel of the ASR-9. In this depiction, NWS levels 2 and 4 have been selected and displayed in "summation" mode. In this display mode, all weather areas with reflectivity above the upper threshold (in this case, level 4) are displayed with the more intense brightness modulation, while all weather areas with intensity between the lower (in this case, level 2) and upper threshold are displayed with a lighter intensity modulation. The ASR-9 also has an alternate "discrete" display mode. In this mode, two of the six NWS levels are displayed with two levels of brightness. The left-hand side of Figure 2 is a simulated ASR-9 weather display in "discrete" mode for selected levels 3 and 5. The right-hand side of Figure 2 shows the same weather viewed in ASR-9 "summation" mode for comparison. Although only two levels are actually displayed in discrete mode, the concentric nature of storm reflectivity contours permits identification

of up to four different reflectivity levels. Clearly, the ASR-9 presents a more detailed and reliable indication of storm reflectivity than earlier ASRs.

During the period July 1988 through November 1988, data from an actual first-production ASR-9 in operation at the Huntsville, Alabama airport was acquired via phone line by Lincoln Laboratory. Although much of the data were acquired while the contractor was performing field test evaluations and prior to FAA acceptance of the system, the ASR-9 data used in this assessment appeared valid. During this same period, Lincoln Laboratory operated a modified ASR-8 radar known as FL-3 (FAA/Lincoln Laboratory 3) as well as the MIT C-band pencil beam weather radar. The MIT radar system was dismantled in October 1988 to fulfill a prior commitment and thus was unavailable for data acquisition after September 1988. Computer software facilities were developed to allow simulated ASR-9 weather reports to be generated using data from these two radars. Simultaneous data acquisition from these "truth" radars provided two independent calibrated sources of radar data for comparison against the output of the ASR-9 weather channel. A limited amount of data from the nearby NWS weather radar were also obtained, but a variety of factors such as 5-minute update rate, clutter contamination, unknown calibration, and data interruption during periods of severe weather made these data unsuitable for assessing the performance of the ASR-9 weather channel.

On August 4, 1988, an isolated "air-mass" convective thunderstorm occurred in the vicinity of the Huntsville airport. Figure 3 shows the output from the ASR-9 weather channel contrasted with simulated ASR-9 outputs using data from the FL-3 and MIT radars for this weather event. Color is used to display all six of the NWS levels simultaneously. The length of time required for the MIT pencil beam to completely scan the same volume of space subtended by the broad elevation ASR-9 fan beam necessitated a restriction on the azimuthal extent being sampled. As can be seen from the close correlation with the "truth" radar outputs, the ASR-9 weather channel appears to perform according to specification and accurately produces the required six-level output.

Two other events during the month of August also showed excellent correlation. However, analysis of subsequent weather events revealed an approximate 3 dB difference in reflectivity between the ASR-9 and FL-3 radars. This bias was independent of range and reflectivity level, suggesting a simple calibration difference between the two radars. Since the ASR-9 data were obtained while the contractor was performing adjustments associated with field testing and evaluation, it was not possible to identify the exact source of error. An additional set of FL-3 based ASR-9 emulations were generated incorporating a 3 dB calibration compensation for all FL-3 data acquired after September 1, 1988. This allowed more meaningful side-by-side comparisons of weather reports between the two radars.

A simple computer-automated differencing technique produced statistics showing the amount of difference between the ASR-9 weather channel product and the FL-3 based emulation for each 1.4 degree by 0.5 nmi resolution cell; the computer program essentially "subtracts" an FL-3 based ASR-9 emulation from its corresponding actual ASR-9 report. The principal finding of this report is summarized in Table 1 which lists the ensemble average probabilities that the ASR-9 and the FL-3 emulations of the ASR-9 weather channel agree to within one NWS level. These statistics were generated for each of the six NWS levels and for both uncompensated and compensated FL-3 data sets.

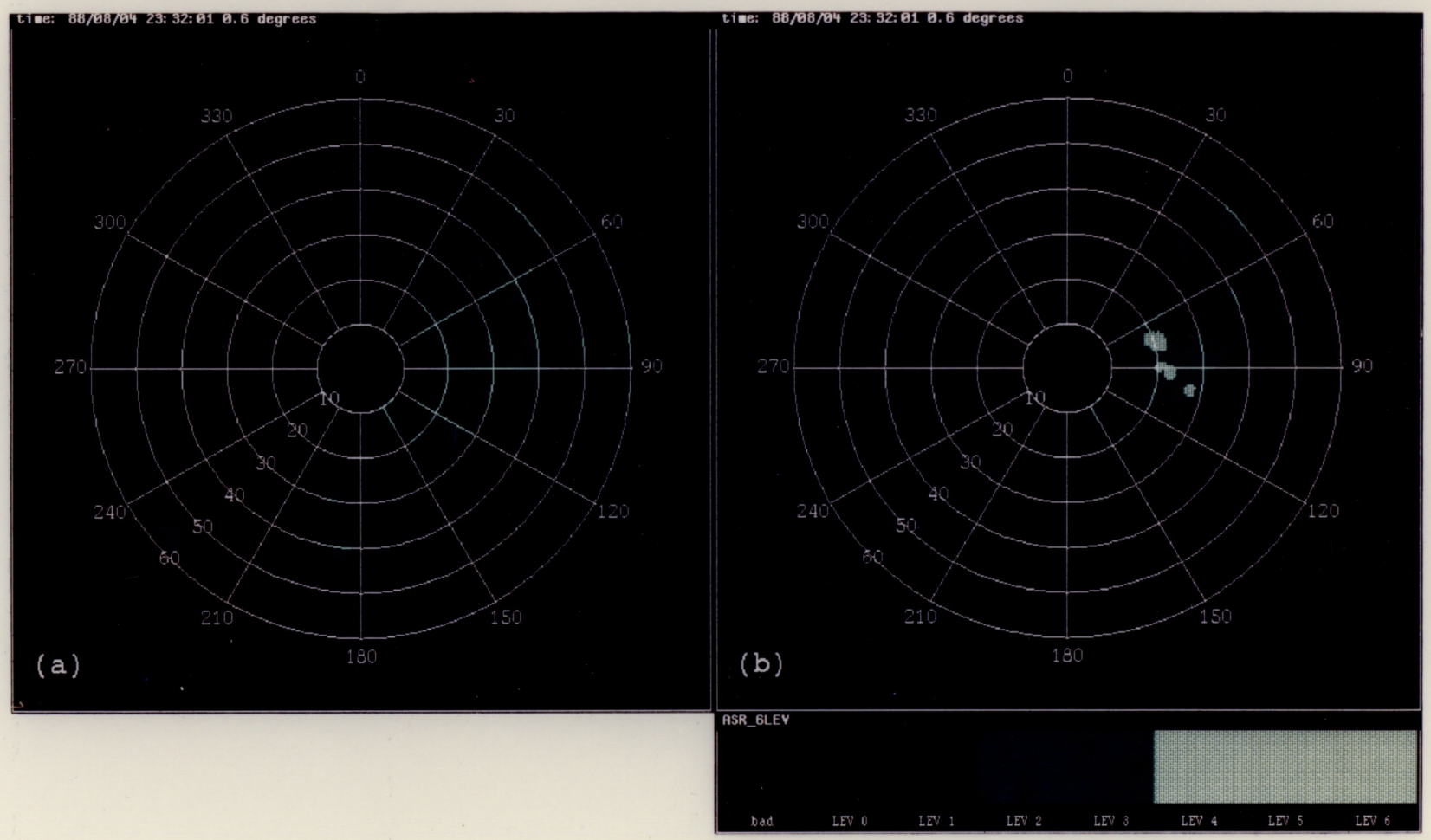

Figure 1. Simulated weather display from (a) current ASR systems and (b) ASR-9 weather channel (summation mode)

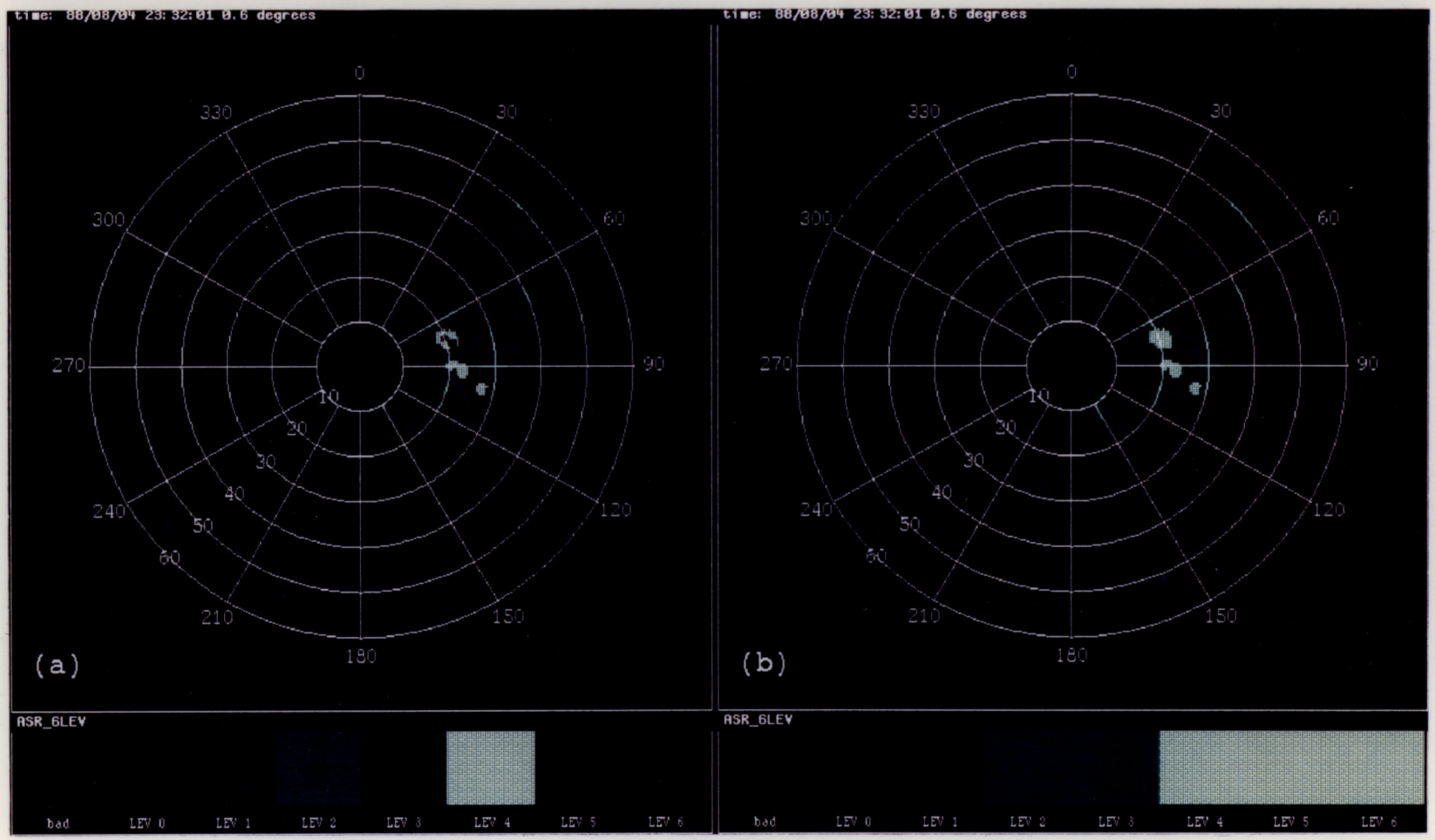

Figure 2. Simulated weather display from (a) ASR-9 weather channel (discrete mode) and (b) ASR-9 weather channel (summation mode)

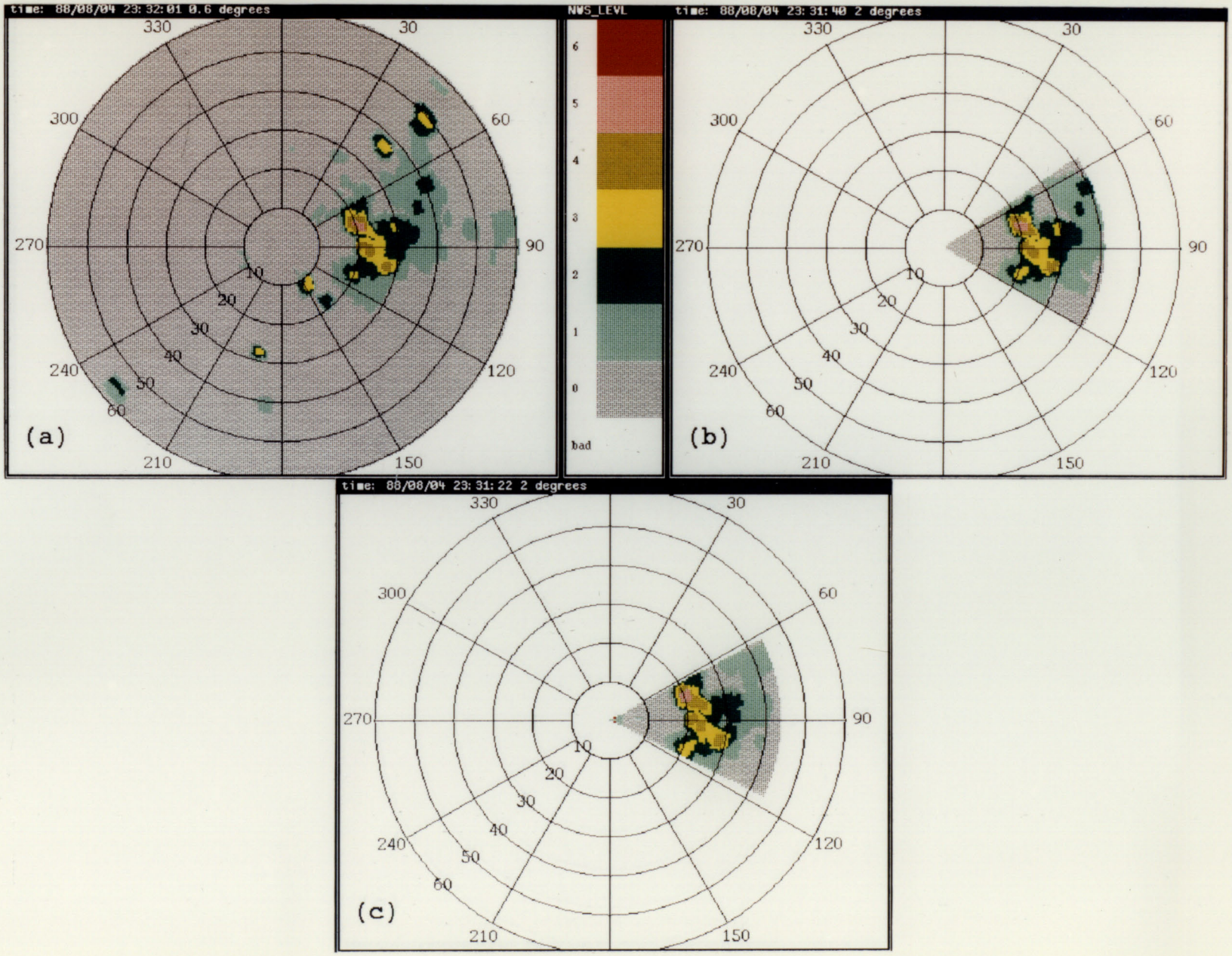

Figure 3. Comparison of six-level output from (a) ASR-9 weather channel, (b) FL-3 based emulation, and (c) MIT based simulation.

Level "0" refers to reflectivities less than the lower threshold for level 1.

TABLE 1.

ENSEMBLE PROBABILITY THAT ASR-9 AND FL-3 EMULATION PRODUCTS AGREE TO WITHIN ONE NWS LEVEL

NWS Level	Unadjusted emulation data	Emulation data increased 3 dB
0	.999	.995
1	.999	.996
2	.957	.956
3	.992	.993
4	.872	.981
5	.782	.970
6	.928	.982

Table 1 shows that when calibration differences were removed, the ASR-9 correctly reported weather reflectivity levels (to within one NWS level) more than 95% of the time for all levels.

Figure 4 is a graphical representation of the amount of agreement between the ASR-9 and FL-3 emulations. In this figure, positive report errors indicate cases where the FL-3 emulation data reported lower reflectivity levels than corresponding ASR-9 data. Clearly, without compensation for the 3 dB calibration difference encountered in data obtained after September 1, the distributions show an obvious bias, while with compensation, report differences decrease and the distribution becomes more symmetric about zero. *Based on the assumption that the 3 dB bias between the ASR-9 and the FL-3 radar reports is due to a simple calibration offset, we conclude in this report that the ASR-9 is operating as specified and that it provides an operationally useful weather product.*

Although the results of this study suggest that the ASR-9 weather channel is performing according to specifications, there are a few areas where additional research and testing may improve the performance of the ASR-9 weather channel:

(1) Optimize beamfill loss correction.

In many regions where the ASR-9 will be deployed, the height of typical storms may not reach a sufficient altitude to completely fill the broad elevation fan beam. This problem is most acute at far ranges, and if uncorrected, the actual reflectivity of these storms may be underestimated. To compensate for this, the ASR-9 uses a region-specific storm reflectivity model to calculate a range-dependent weather reflectivity threshold correction. These storm models and the resulting beamfill loss corrections need to be optimized to accurately reflect the typical storm structures encountered within the particular climatic region of the United States. A five-step method for developing these regional storm models has been proposed by Lincoln Laboratory and is described in more detail later.

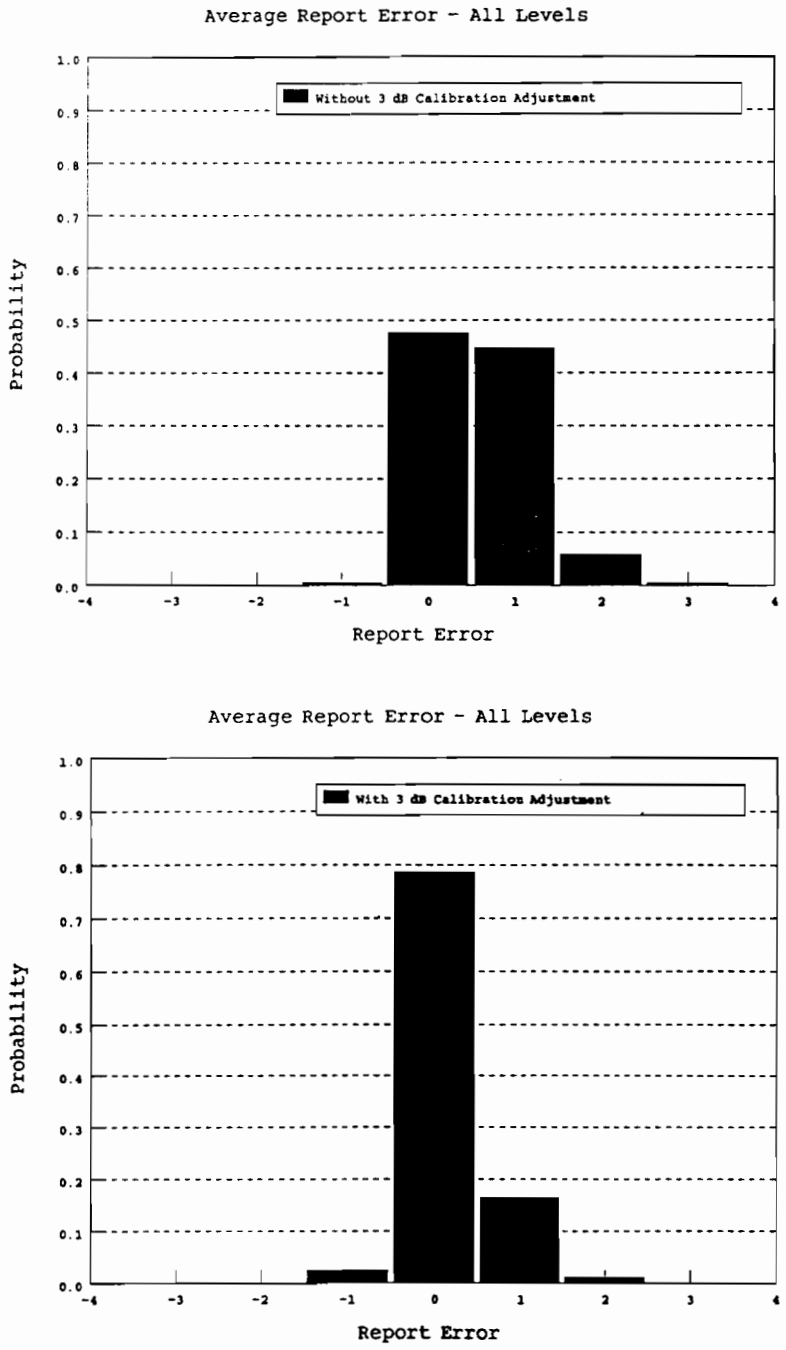

Figure 4. Graphical representation of the probability of agreement between the ASR-9 and FL-3 emulation data offset by 0 and 3 dB for all NWS levels.

(2) Investigate polarization effects.

Although the results of this study found no obvious signs of ASR-9 weather reflectivity error due to polarization loss, numerous studies have shown this to be a potential problem. In order to further investigate these effects, Lincoln Laboratory will use the FL-3 radar to record simultaneous circular polarized (CP) and linear polarized (LP) data during significant and spatially extensive high reflectivity precipitation events while in Kansas City in 1989. The ASR-9 six-level weather channel emulation facility will then be used to determine the effects of depolarization attenuation on ASR-9 reflectivity estimates.

SECTION 2

BACKGROUND

2.1 ASR-9 WEATHER CHANNEL DESCRIPTION

The ASR-9 weather channel is designed to provide ATC personnel with an accurate, quantized, clutter-free representation of the precipitation field. Its weather products are generated by either a two-level or six-level weather processor. Because the two-level processor is similar to and intended as a back-up to the six-level processor, this section is limited to the description of the six-level processor. The ASR-9 weather channel allows ATC personnel to select and display any two of the six National Weather Service (NWS) levels. The levels are defined in terms of logarithmic reflectivity (dBZ[1]) and are shown in Table 2.

TABLE 2

NWS STANDARD REFLECTIVITY LEVELS

Level	Reflectivity (dBZ)	Rainfall Category
1	18 - 30	Light (Mist)
2	30 - 41	Moderate
3	41 - 46	Heavy
4	46 - 50	Very Heavy
5	50 - 57	Intense
6	57+	Extreme (Hail)

As is the case for previous terminal radars, many ASR-9 system features (frequency, pulse width, peak power, pulse repetition frequency, and clutter rejection) make it well

[1] Z is proportional to volume reflectivity (e.g., m^2/m^3) with the wavelength dependence (λ^4) for Rayleigh scatterers removed. Conventionally, Z is expressed in units of mm^6/m^3.

suited for weather observations. System features adverse for weather measurement in previous ASRs, have been either changed or compensated for in the ASR-9 weather channel. The following paragraphs outline features of the ASR-9 that facilitate weather reflectivity measurement.

Previous and current ASRs receive both weather and target information from the same channel. However, when these radars operate with circular polarization (CP), the weather echo power return is decreased by as much as 18 dB to improve target detection. This reduction of weather echo power in the target channel is caused by the reversal of polarization sense when the transmitted signal is reflected by spherical rain drops. To allow the simultaneous optimum detection of both aircraft targets and weather, the ASR-9 has a receiver channel for weather reflectivity measurement (Figure 5) and another receiver channel for aircraft detection. The weather channel receives orthogonal sense polarization when the radar is operated in CP to match the polarization of the weather signal. When linearly polarized (LP) signals are transmitted, the weather channel receives same sense LP via the target channel A/D converters.

The ASR-9 antenna rotates at 12.5 RPM and utilizes range-azimuth selectable dual receiving beams ("high" and "low"). The angular extent of the 3 dB elevation beamwidth is approximately 6 degrees for both beams, with the high beam displaced by 3.5 degrees with respect to the low beam. The peak of the low antenna beam is typically placed at 2.0 degrees above the horizon, which places its lower -3 dB edge on the horizon. The high beam is selected for near ranges (typically less than 18 nmi) in order to reduce the impact of ground clutter with the low beam selected thereafter. The wide elevation beamwidth and rapid scan rate are dictated by the ASR-9's primary function of detecting and resolving rapidly-moving aircraft at altitudes up to 35,000 feet, over a 60 nmi radius. This configuration allows a large volume to be sampled, while providing a sufficiently rapid update rate (approximately 5 seconds for aircraft targets). Radar echoes are sampled at 1/16 nmi [115.8 m] range intervals over 60 nmi [111.1 km]. There are two coherent processing intervals (CPIs) per azimuthal beamwidth (1.4 degrees) for a total of 256 azimuth intervals. The two CPIs consist of one set of 8 pulses at one pulse repetition frequency (PRF) and one set of 10 pulses at a higher PRF. The weather processor takes advantage of the alternating PRF strategy to filter second-trip echos by comparing the reflectivity estimate from the 8- and 10- pulse CPI then choosing the lowest reflectivity estimate for that CPI pair (this assumes that second-trip weather will not be detected for both PRFs).

Figure 5 is a simplified block diagram of the ASR-9 weather channel processor. The weather processor incorporates coherent ground clutter suppression using four clutter filters that produce clutter attenuation of zero to 49 dB. One of the four filters is chosen for each range-azimuth cell based on the weather reflectivity and a stored clear-day clutter map. This allows for sufficient signal to clutter ratio, while minimizing the degradation of the weather reflectivity estimate due to filter attenuation.

After passing through the clutter filters, data are converted to equivalent NWS six-level intensities through the use of a memory-resident thresholding map. The map contains thresholds as a function of range, polarization, receiving beam, and sensitivity time constant (STC). Storms of limited vertical extent may not fill the entire ASR-9 fan beam, resulting in an underestimation of the elevation-integrated storm reflectivity.

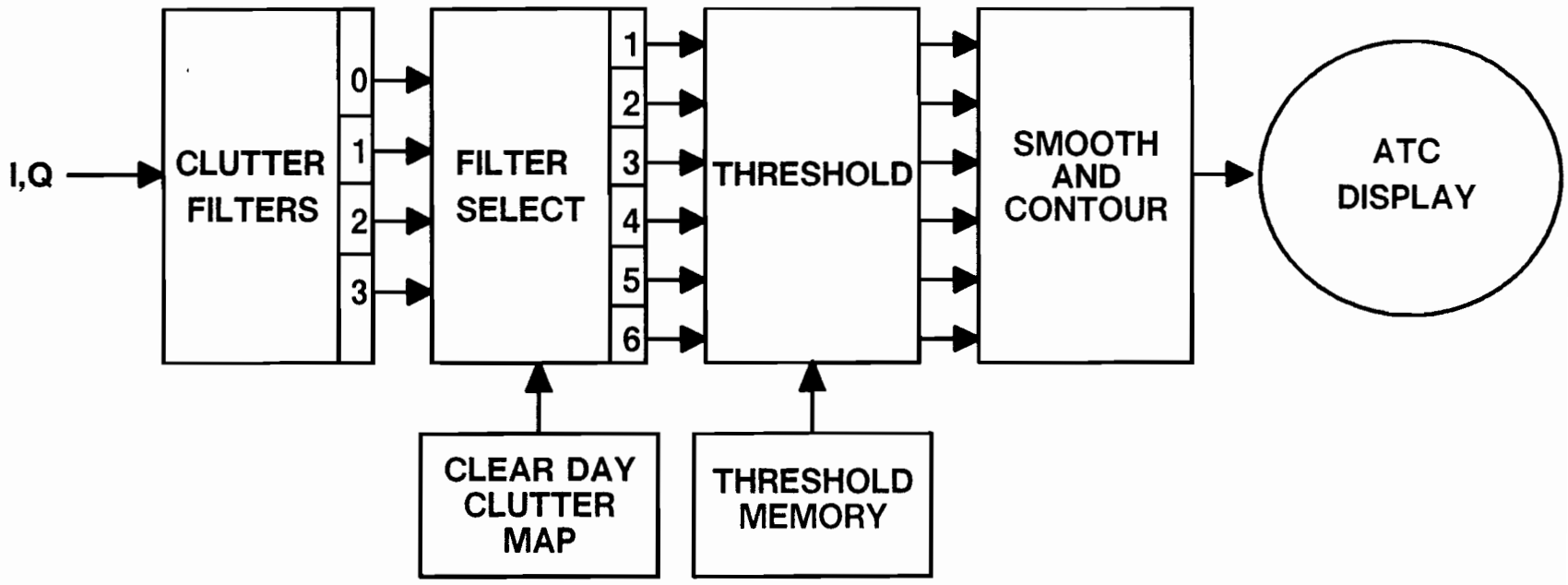

Figure 5. ASR–9 weather channel block diagram.

To correct this bias, the weather processor thresholds are adjusted as a function of range, using a predetermined storm reflectivity model. The threshold adjustments may be changed, although not in real time, to accommodate other storm models. The storm model used by the contractor for the Huntsville climate assumed a storm of constant reflectivity from the ground up to 4 km in elevation, then decreasing 3 dB per km above 4 km.

To overcome the inherent noisiness of the reflectivity estimates, a sequence of spatial and temporal smoothing filters is employed. First, the data are smoothed in range over 1 nmi intervals by passing the data through a median filter. This filter selects the highest level exceeded in at least 8 out of 16 range gates, and is repeated at 0.5 nmi increments. Then, the data are passed through a three-stage smoothing and contouring processor. The stages of smoothing are as follows: (1) the median level from three consecutive scans is computed for each range-azimuth cell, (2) the highest level found in at least "WWW" (an adjustable parameter typically equal to 5) of a nine-cell cluster centered about the weather cell is computed for each range-azimuth cell, and (3) the highest level of the nine-cell cluster centered about the weather cell is assigned to that cell. The spatial filters have the added benefit of reducing the impact of clutter-censored cells and enlarging regions of the higher reflectivity weather.

The weather channel output consists of cells 1.4 degrees in azimuth by 0.5 nmi in range (256 azimuths by 120 range samples per azimuth, for a total of 30,720 cells per plan view), generated by processing echoes received over a 2 nmi range and a 4.2 degree azimuth interval.

2.2 PERFORMANCE ISSUES

The following four features of the ASR-9 weather channel play important roles in producing weather displays that are accurate and easily interpreted by air traffic controllers. Brief descriptions of these issues follow.

(1) Clutter filtering
(2) Beamfill corrections
(3) Smoothing and contouring
(4) Polarization matching

Clutter Filtering: Appendix B of the ASR-9 Weather Channel Test Report[2] contains an excerpt from a report that addressed the impact of ground clutter on the ASR-9 weather channel. This report showed that the adaptive clutter filters, together with the spatial and temporal smoothing, should result in accurate precipitation reflectivity measurements even in the presence of intense ground clutter at short range. The results of the ASR-9 assessment generally support these findings.

[2] D.C. Puzzo et al., "ASR-9 Weather Channel Test Report", ATC-165 (Report No. DOT/FAA/PS-89/3), MIT Lincoln Laboratory (April 1989).

In Huntsville, significant ground-clutter breakthrough was occasionally observed during the night and early morning hours on the ASR-9 weather display when no weather was present. This problem has been attributed to anomalous propagation (AP). A problem common to ground-based radars, AP occurs when certain atmospheric conditions cause radio waves to bend down toward the earth, causing ground echoes to appear on the radar display in regions that are usually free of ground echoes. The ASR-9 weather channel ground clutter suppression technique, based on a fixed, clear-day clutter map, does not generally suppress AP-based ground clutter returns.

The AP problem may be treated operationally by simply turning off the weather display during occurrences of AP. This would not compromise safety since the conditions leading to AP are not conducive to thunderstorm generation. However, two methods were considered for removing AP clutter from the ASR-9 weather channel products: (1) identification of clutter breakthrough based on spatial characteristics of ground clutter, and (2) identification of clutter breakthrough based on spectral characteristics. Both methods would require changes to the weather channel's processing algorithms. Results suggest that clutter identification based on its spectral characteristics may significantly reduce AP based clutter breakthrough while having a minimal effect on weather reflectivity estimates.

Beamfill Corrections: The static storm model used for calculation of the ASR-9 beamfill corrections will produce errors when the actual storm vertical reflectivity profile deviates from that of the model. There are two major factors that govern the effectiveness of beamfill correction algorithms: (1) the particular phase of the storm's life cycle during which it is observed; and (2) the atmospheric processes governing the vertical reflectivity distribution in the storm. A single storm model will not accurately characterize the actual storm over its entire life cycle, although it may during one particular phase. In spite of this, previous research has shown that relative errors between corrected and uncorrected ASR reports would generally be no larger than 2 to 3 dB, corresponding to at most one NWS level.

Smoothing and Contouring: The smoothing algorithms used in the ASR-9 weather processor are intended to minimize statistical fluctuations of the weather maps. The issues of ASR-9 weather channel smoothing and contouring were previously addressed in a previous report[3] and are also discussed in Appendix B of the ASR-9 Weather Channel Test Report. The report concluded that the temporal and smoothing filters of the ASR-9 significantly reduce statistical fluctuations of the weather reports and produce a display that is stable from scan to scan.

Polarization Matching: Normally, the ASR-9 transmits and receives vertical polarization (VP). However, when there is reflectivity greater than level 3 covering a large area, the ASR-9 transmits and receives circularly polarized (CP) signals through its target channel to reduce the interference from rain echoes. The target channel is set to receive same sense CP, while the weather channel allows opposite sense reflected signals to come through by receiving opposite sense CP. Theoretical research has shown that

[3] M.E. Weber, "Assessment of ASR-9 Weather Channel Performance: Analysis and Simulation", Project Report ATC-138 (Report No. DOT/FAA/PM-86-16), MIT Lincoln Laboratory (31 July 1986).

when CP is transmitted during heavy precipitation, the returned echoes may deviate from true opposite sense CP. Although this effect was not observed with the limited amount of ASR-9 CP data, this deviation could lead to an underestimation of the true storm reflectivity.

SECTION 3

ANALYSIS METHODS

Figure 6 shows the geographical location of the sensors used to collect data during the ASR-9 field test at Huntsville, Alabama. Although NWS radar data were recorded for possible reference, the typical horizon-scan mode, lack of ground clutter rejection, and low update rate of the NWS radar made its data unsuitable for assessment of the ASR-9 weather channel performance. The MIT pencil-beam radar and FL-3 fan-beam radar were situated approximately 1 nmi west of the ASR-9 and recorded data simultaneously during occurrences of precipitation.

Figure 7 summarizes the derived radar data products used for the ASR-9 weather channel assessment. Data from the MIT and FL-3 radars were used as input to separate computer programs which simulated the processing of the ASR-9 weather channel and produced corresponding six-level output with the same 1.4 degree azimuth by 0.5 nmi range resolution as the ASR-9. The 2-dimensional (range-azimuth) weather reflectivity map produced by the ASR-9 represents only one realization of the 3-dimensional (range-azimuth-elevation) reflectivity field, i.e., fan-beam elevation-integrated. The 1.4 degree vertical resolution of the MIT radar pencil beam permits generation of alternate 2-D reflectivity realizations. For each of the weather events used in the assessment, vertical profile maximum, vertical profile average, and single horizon scan (similar to NWS) criteria were used to create alternate weather reflectivity products. These alternate products are useful in assessing the pertinence of the ASR-9 weather product in terms of ATC concerns.

Analysis methods are summarized in Figure 8. The various derived radar products were first converted to a Cartesian, ASR-9 based coordinate system with 1 nmi grid resolution. These data were then stored as disk files on the computer. Six-level color PPI plots of the various products were then produced to allow visual inspection and comparison. A computer-automated PPI differencing facility was then used to produce a second set of color PPI plots, representing the amount of report error (expressed as a number of NWS levels) between a reference product (the ASR-9 six-level output) and one of the comparison products, e.g., FL-3 based ASR-9 emulation. A statistical table was also generated for each computer-automated comparison displaying reflectivity level difference probabilities as a function of the ASR-9 reflectivity level. Ensemble statistics were then computed from the individual tables.

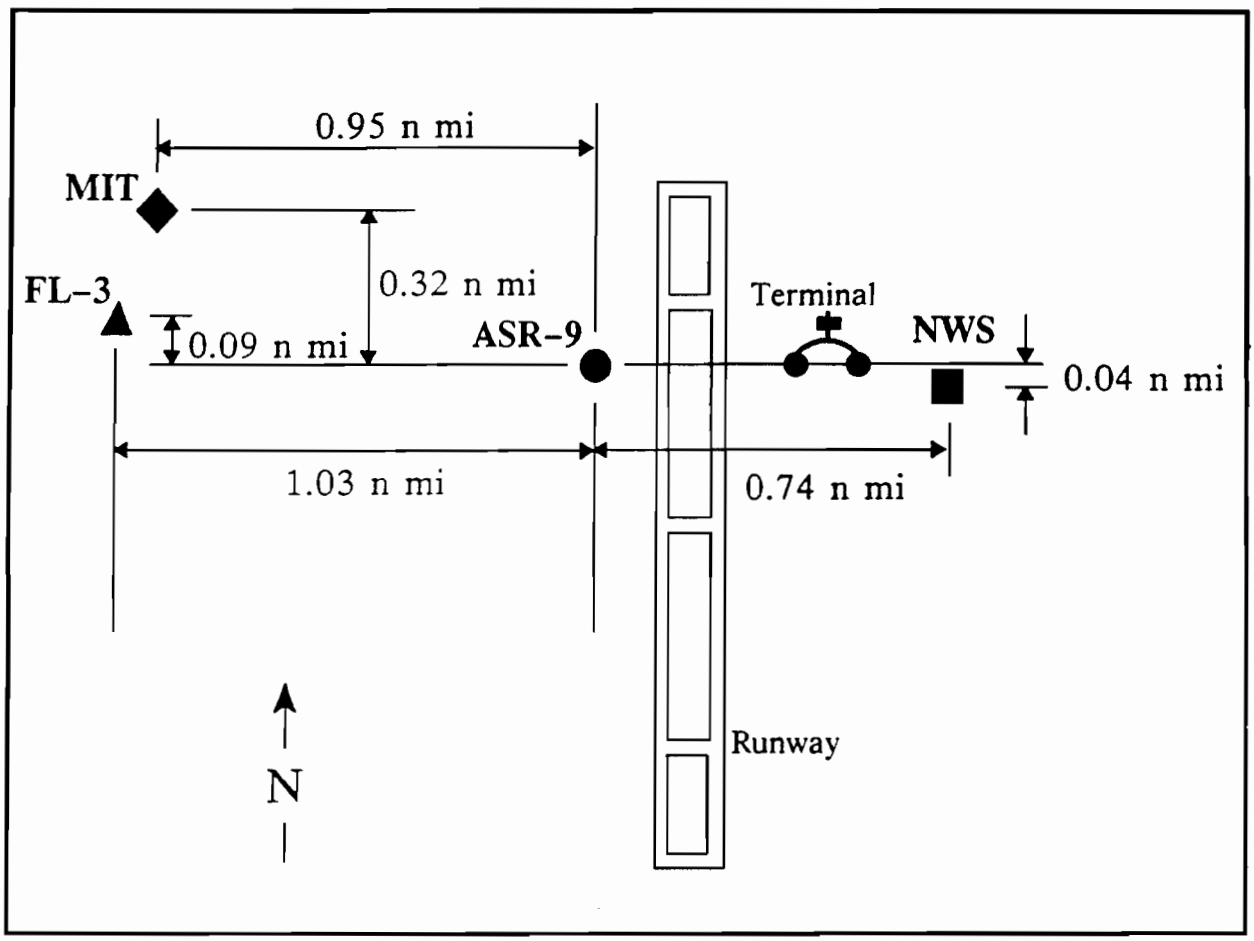

Figure 6. Sensor locations at the Huntsville, Alabama airport.

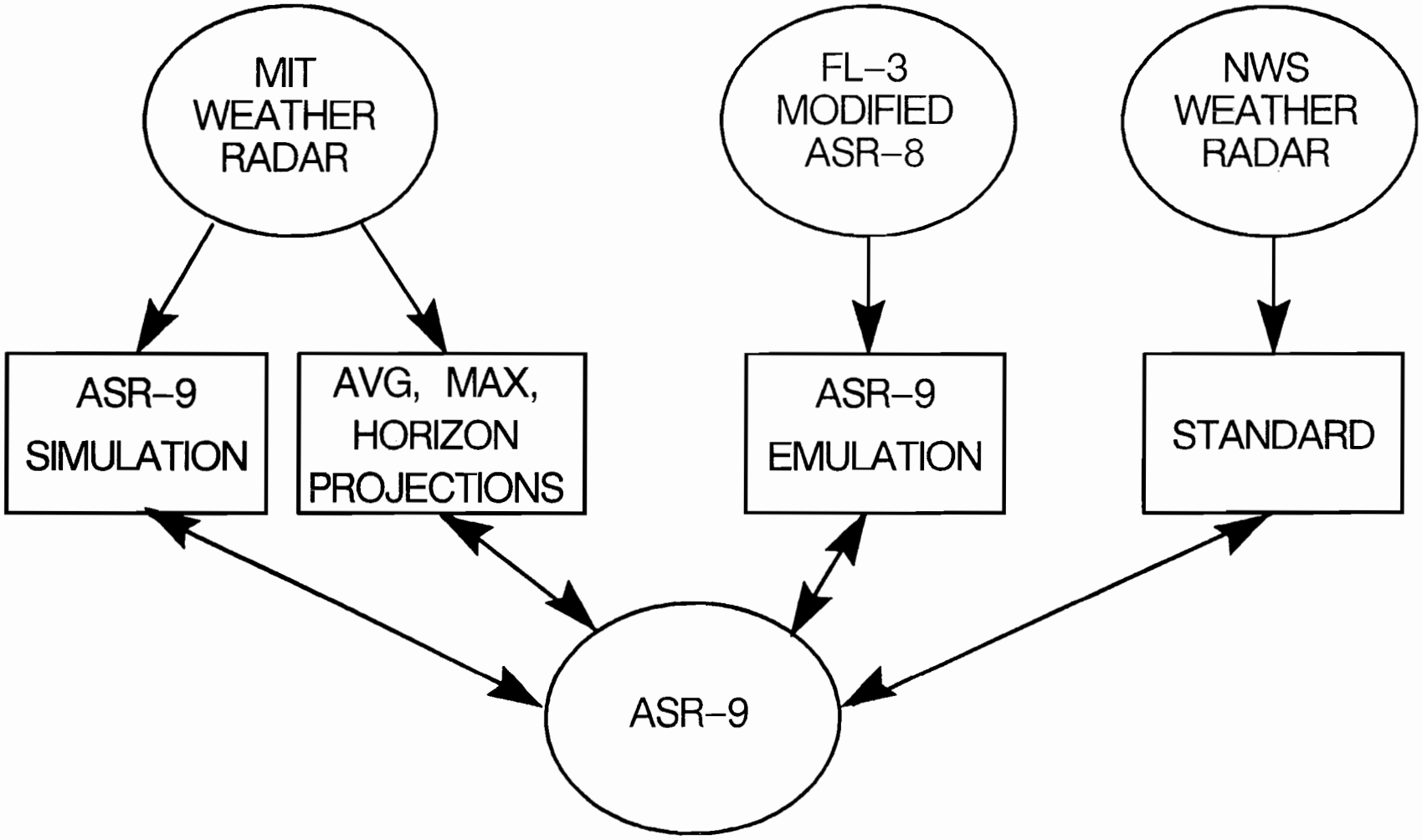

Figure 7. Radar data products used for ASR-9 weather channel assessment.

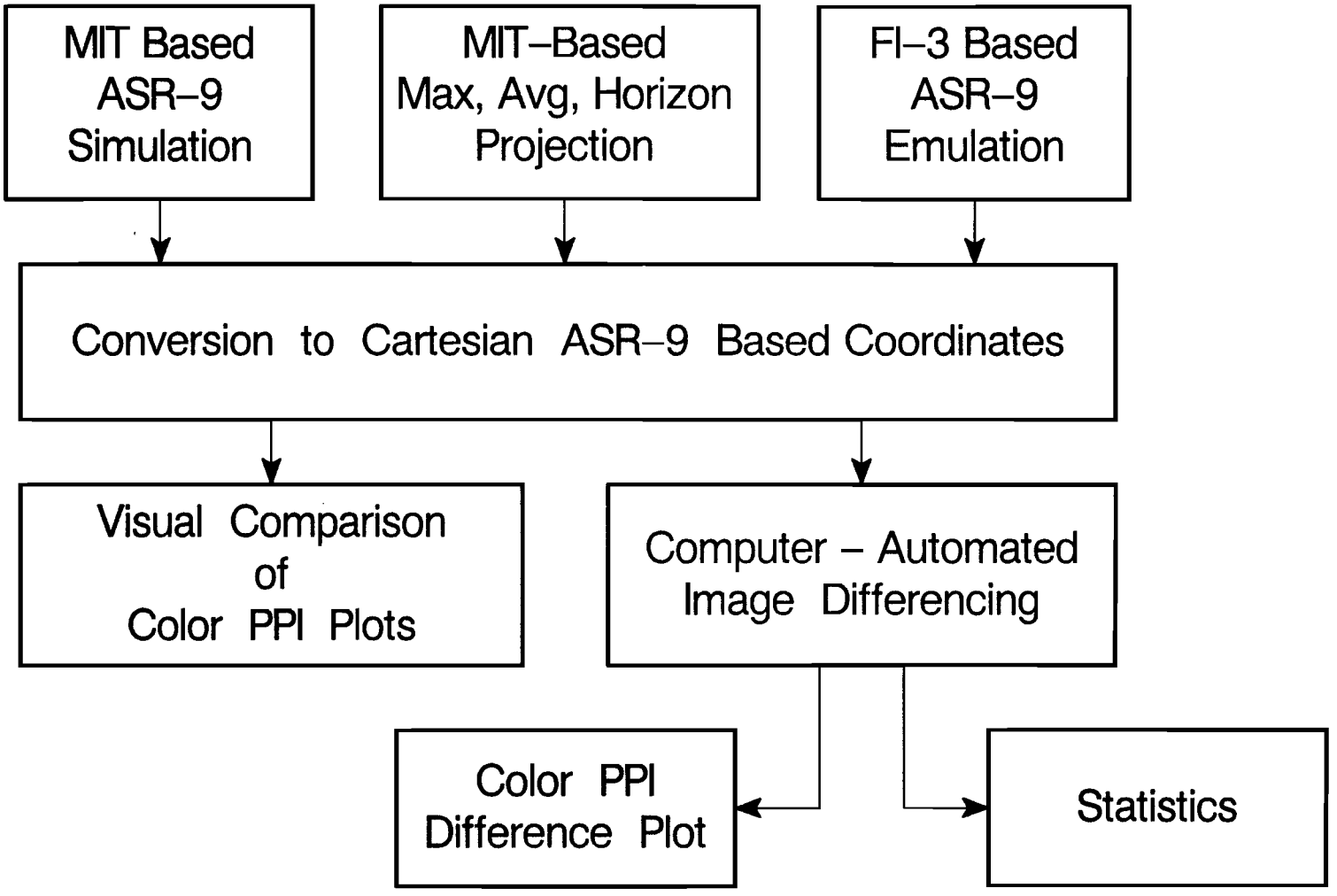

Figure 8. Flow diagram of analysis methods used during ASR–9 weather channel assessment.

SECTION 4

SUMMARY AND CONCLUSIONS

ASR-9 weather channel data were recorded simultaneously with data from the MIT pencil-beam weather radar and the FL-3 (ASR-9 emulation) radars in Huntsville, Alabama. During this time, the ASR-9 Field Test and Evaluation was underway, so the ASR-9 was not certified. A severe drought occurred in the Huntsville area during 1988, resulting in only nineteen weather events being recorded, processed, and analyzed for inclusion in this assessment. However, these data allowed for analysis of four basic types of weather: stratiform rain, air-mass thunderstorms, squall lines, and cold fronts.

Separate cases for the two- and six-level processor were analyzed because the processors are independent subsystems and do not provide weather data simultaneously to a remote site. Operationally, the six-level weather processor is the primary source of weather while the two-level weather processor is the back-up source. This is reflected in the greater amount of six-level weather data available for assessment.

Separate cases for the ASR-9 operating with circular polarization and linear polarization were analyzed for two reasons. First, the front-end path losses and STC functions differ, depending on the polarization and processor chosen. Accordingly, the two- and six-level processors compensate for RF path losses and STC functions. Second, there may be polarization loss dependent on the sense of polarization (orthogonal or same sense) of the receiver and the ellipticity of the rain drops. Perfectly spherical raindrops propagate opposite sense polarized signals back to the radar.

The nineteen weather data sets were used to address two primary issues:

(1) Does the ASR-9 weather channel, as implemented, perform according to FAA specifications?

(2) Does the ASR-9 weather channel adequately represent weather reflectivity pertinent to ATC?

To determine whether or not the ASR-9 weather channel performs according to specification, ASR-9 weather channel data were compared both subjectively and quantitatively with:

(1) Simulated ASR-9 weather data using pencil-beam (MIT) radar data.

(2) Emulated ASR-9 weather data using fan-beam (FL-3) radar data.

The first three cases from August 1988 included both MIT based simulation and FL-3 based emulation data. Subsequent cases included only FL-3 based emulation data for comparison to ASR-9 weather products. Analysis of the first three cases shows good agreement between ASR-9, MIT based simulation data, and FL-3 based emulation data. Analysis of all subsequent cases indicates about a 3 dB difference between ASR-9 and FL-3 based emulation data. This bias was independent of range and reflectivity level, suggesting a simple calibration difference between the two radars. When the FL-3 based

emulation was adjusted to compensate for the 3 dB difference, results showed good agreement between ASR-9 and FL-3 based emulation data.

The six-level output from the ASR-9 weather channel is compared with the FL-3 based emulation (adjusted by 3 dB) in Figure 9 for a squall line event that occurred at the Huntsville airport on November 26, 1988. This organized line of intense thunderstorms propagated from northwest to southeast, passing directly over the ASR-9. As can be seen from the figure, the ASR-9 output correlates well with the FL-3 emulation output and produces a weather display that remains stable even in the presence of significant ground clutter in the vicinity of the airport.

ASR-9 weather channel performance was consistent with both expected and emulated performance when compensation for an observed 3 dB calibration error was incorporated, indicating that the ASR-9 weather channel was implemented according to FAA specifications. Ensemble statistics based on all six-level data after August 1988 indicate reflectivity levels reported by the ASR-9 were within one level of the emulation data at least 78.2% of the time when compared with unadjusted emulation products and at least 95.6% of the time when compared with adjusted emulation products. It should be noted that report errors arising from a simple calibration offset will not be uniform, given the coarse, nonlinear partitioning of the NWS reflectivity levels.

To determine whether or not the ASR-9 weather channel adequately represents weather reflectivity, ASR-9 weather channel data were compared both subjectively and quantitatively with three representations of data obtained from the MIT pencil-beam weather radar based on:

(1) Maximum reflectivity observed over the vertical extent of the storm.
(2) Average reflectivity observed over the the vertical extent of the storm.
(3) Reflectivity observed at the horizon (NWS equivalent).

These specific measurement criteria were chosen because they may all be relevant from an ATC viewpoint. Comparisons show that the ASR-9 weather channel data agree generally within one level of the maximum, average, and horizon scan (NWS equivalent) reflectivity data. Figure 10 is an example of the three alternate reflectivity representations along with the ASR-9 output for the convective air-mass thunderstorm event of August 4, 1988. A small region of level 6 can be seen in the PPI plot of the vertical profile maximum reflectivity. The absence of level 6 in each of the other PPI plots suggests the presence of an elevated reflectivity core of limited vertical extent.

Strongest agreement was found between ASR-9 data and maximum and horizon-scan reflectivity data when the storm reflectivity core was close to the ground. This was expected because the beamfill correction is based on the contractor's storm model which assumes the maximum reflectivity of the storm is between the ground and 4 km. Stronger agreement was found between ASR-9 data and average reflectivity data when the storm reflectivity core was aloft. Since storm structures vary between geographical regions and between times during their individual life cycles, the static storm model used for the ASR-9 beamfill correction cannot be expected to correlate exactly with any one storm model for all weather observed.

The ASR-9 weather channel gives controllers access to weather reflectivity information quantized in six NWS levels and updated every 30 seconds. The novel processing features incorporated in the weather channel include spatial and temporal smoothing and elimination of second-trip weather echoes and ground clutter. The ASR-9 weather products are based on observations from the entire volume scanned by the ASR-9 antenna, thus, the controller will have timely weather information from storms developing aloft. Overall, the ASR-9 should represent a significant improvement over its predecessors in providing air traffic controllers with useful weather data.

SECTION 5

ADDITIONAL RESEARCH

The ASR-9 weather channel operating in Huntsville appears to give a useful representation of weather reflectivity within the 60 nmi operational range. The apparent 3 dB discrepancy is most likely caused by a difference in calibration between the ASR-9 and FL-3 emulation radars. Without a simultaneous calibration of these two radars, using common calibration equipment and a common calibration target (e.g., sphere, corner-reflector), it may not be possible to reconcile this difference. For example, just a 0.5 dB error in the antenna gain measurement for each radar could result in as much as a 2 dB difference in the reflectivity measured by each.

Two other issues relating to the ASR-9 weather channel should be pursued because of their possible impact on weather channel performance. These are optimization of the beamfill correction implemented by the weather processor, and losses due to both elliptical and opposite sense polarization.

5.1 OPTIMIZATION OF BEAMFILL CORRECTION

The Huntsville climate represents only one of the climatic regions that will be encountered by ASR-9 systems. Although the results herein found that ASR-9 products agreed to within one NWS level of profile maximum, profile average, and horizon-scan reflectivity data, it is clear that the amount of agreement is dependent on the storm characteristics and the appropriateness of the static storm model used to determine the range-dependent beamfill correction. Optimal performance from the beamfill correction can only be obtained if the static storm model accurately characterizes the ensemble of storms that the ASR-9 is likely to encounter in its region. The following steps for developing region-specific storm models have been proposed and are currently being researched by Lincoln Laboratory:

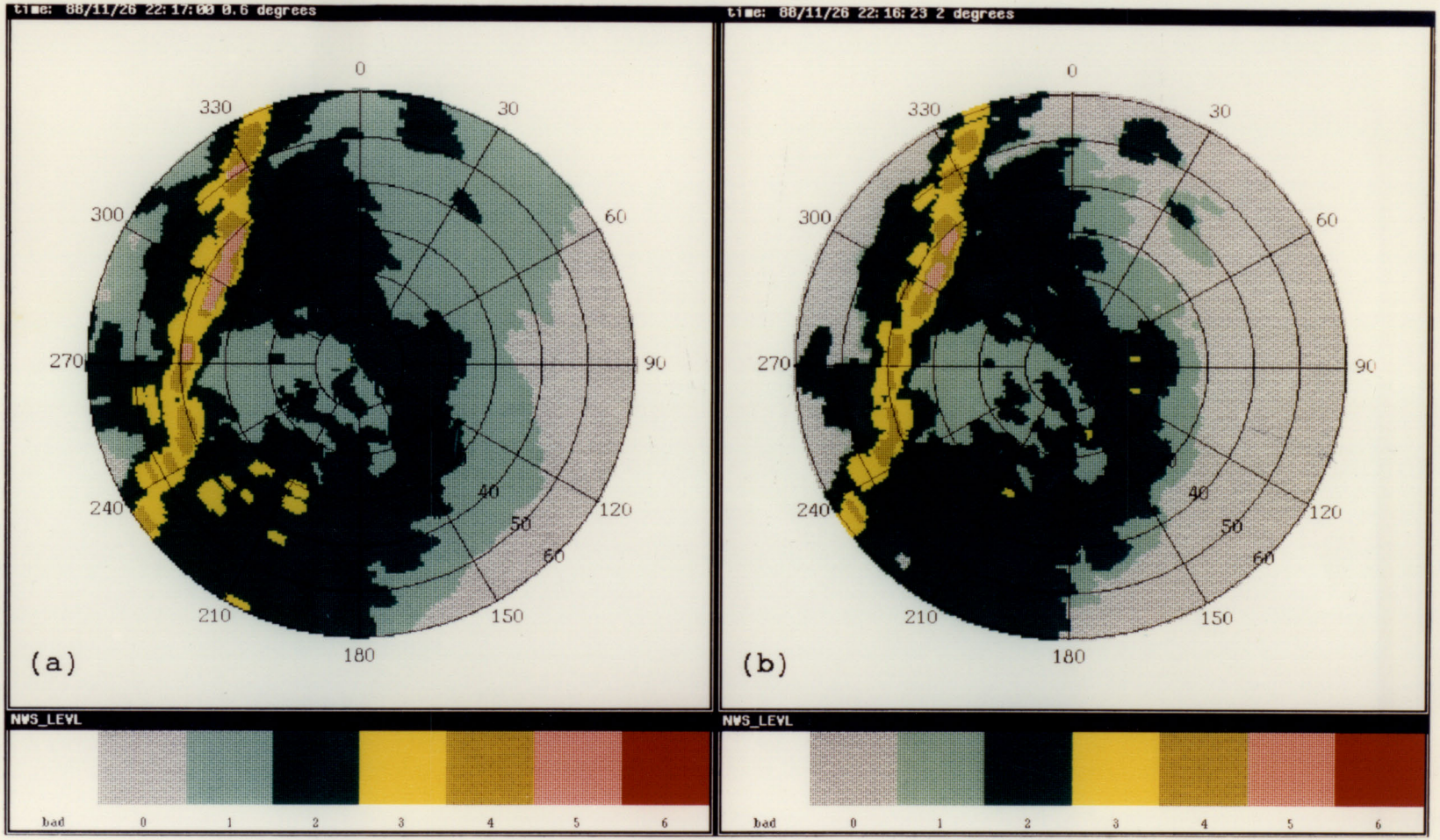

Figure 9. Comparison between (a) ASR-9 six-level, and (b) FL-3 emulation increased by 3 dB for squall line event of November 26, 1988.

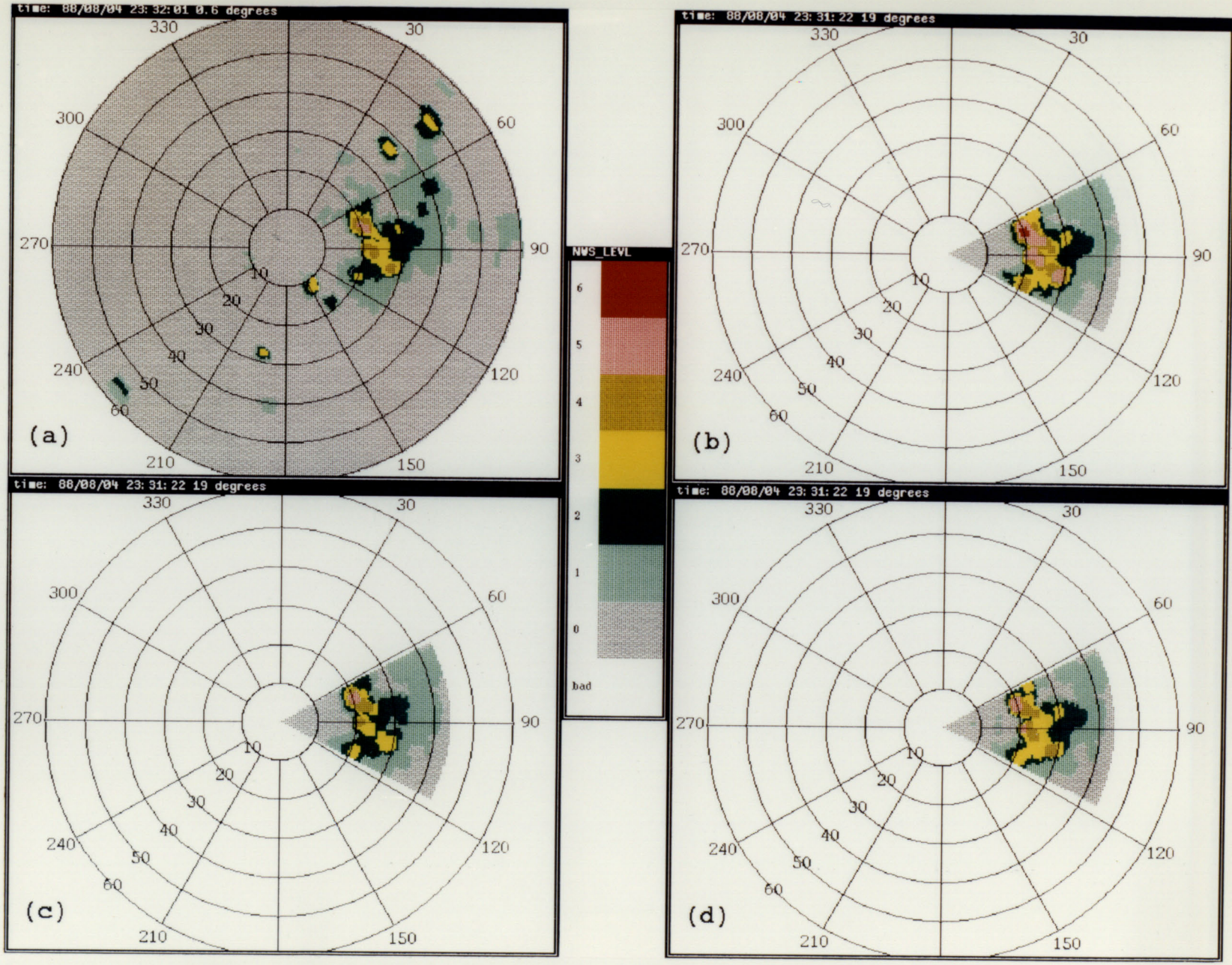

Figure 10. Comparison between (a) ASR-9 six-level, (b) MIT based profile maximum projection, (c) MIT based profile average projection, and (d) MIT based horizon scan reflectivity products for convective storm event of August 4, 1988.

(1) Determine the desired weather reflectivity product.

The most conservative approach would be to always report the maximum reflectivity at any altitude. However, the maximum reflectivity product is insensitive to the vertical extent of the maximum reflectivity region, and hence gives no indication of the percentage of the profile over which the most hazardous conditions will prevail. Since this may not always be representative of conditions encountered by an aircraft along its glide slope, such a product could over-warn, but at the same time might provide a desirable margin of safety. Different reflectivity parameterizations should be examined to determine the weather product most useful to ATC.

(2) Determine the magnitude of error that may result from an invalid storm model.

This represents a preliminary research step to ascertain the degree of accuracy needed in developing and selecting storm models, as well as the impact of using an invalid storm model in producing the desired weather reflectivity reports. The coarse quantization of the NWS levels would certainly reduce the impact of an invalid model.

(3) Identify geographical regions that could be represented by a single storm model.

The continental United States should be divided into regions where similar atmospheric conditions governing the height and structure of storms prevail. Somewhere on the order of five regions will probably suffice, given the crudeness of the beamfilling correction.

(4) Develop a model for each region based on climate.

The contractor's present model may be appropriate for some regions, and could be adapted for those regions where it is inappropriate. These modifications would incorporate meteorological characteristics of the region such as vertical moisture distribution, cloud base and extent, freezing level, and temperature distribution. If meteorological characteristics of a particular region exhibit large seasonal variation, it may be necessary to develop seasonal models for that region.

(5) Where possible, verify the models by comparison with weather radar data from selected representative sites.

Regional and seasonal storm models developed from climatology should be verified by comparing these models against site-specific models computed from actual radar data recorded at several locations within each region. For example, data recorded by FL-3 and the FAA Terminal Doppler Weather Radar FL-2 (pencil beam) at Kansas in 1989 could be used to generate an optimal beam storm model for that site. This data-derived model would then be compared to the regional model that was developed from climatic data characterizing Midwest thunderstorms.

5.2 INVESTIGATION OF POLARIZATION LOSSES

Although this study found no obvious signs of ASR-9 weather reflectivity error due to polarization loss, numerous other studies have shown this to be a potential problem. Lincoln Laboratory plans to use the FL-3 radar at the Kansas City field site in 1989 to record simultaneous CP and LP data during significant and spatially extensive high reflectivity precipitation. ASR-9 six-level weather channel emulation software will then be used to determine the effects of depolarization attenuation on ASR-9 reflectivity estimates.

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